الهيئة العامة للأبنية التعليمية

# DESIGN OF ELECTRIC STATIONS

*By*

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# Content

# Introduction

**It is important to treat the subject of a design in order to find the best of the best solutions we can find. Therefore, the problem of the design of power stations is one of the vital engineering item, that may be in the circle of our interest.**

**The given book relates to the design process including the basics of the systems in the field besides others. The book talks to engineers and students inside the electrical Power Engineering and helps to a great extent the designers to act better.**

**Finally, the subjects studied here are integrated to cover the problem as a whole while each chapter is an independent flag.**



# Chapter I
# Design Basics

**In the field of design there are some important Basic Rules that must be taken into account first although different solutions can be reached in various concepts. This makes the rules as a basic title more important and they may simplify the complicated problem. This needs a complete information about some items as tailored nest.**

## 1-1 Objective Function

**This means the requirements that must be realized in the final solution of the design. The fundamental conditions for a good design may be shortly indicated below:**

### 1- Simplicity

**The simplicity might be presented in all elements individually or in the final result including the connection, installation, maintenance and operations. The simplicity will be reflected to the inspection and revision needs.**

### 2- Harmony

**The harmony of the components in the design may be required in such a subject due to the security needs in the operations with the danger of the presented HV levels in the stations. This will be reflected on the position of each component, equipment distribution, and the electric connections. The harmony can minimize the risk factor in the level of the design where the best design will prevent any danger, generated from the contents of the station design.**

### 3- Reliability

**The reliability is a significant item specially with electric stations due to the need for continuous flexibility, service duty and the ability for extension.**

### 4- Safety

**The safety controls the operations and installations as well as the maintenance to secure either operators and engineers inside the yard or equipment including insulation, conductors, devices or windings.**

### 5- Protection

**It means the protection against faults which can be appeared and short circuits in yje station or the power system and wrong operations.**

### 6- Stability

**The most important factor in a design may be the stability with either operation or clearing a fault or even during the switching processes The system should be stable for any disturbance or mistakes.**

### 7- Economic

**Engineering design is always depending on the economic solution to cover either normal or emergency operations. Hence, the cost plays a great role in the final result of the design computations to find out the best engineering solution.**

### 8- Minimize the disturbances

**This means that the design could consider the most suitable connections and arrangement in order to minimize the disturbance possibility with operations. This is requires to save the conditions of switching in order to get the most convenient solution.**

### 9- Reduction of operation errors

The connections and wiring should reduce the error factor to the minimum level during operation to bring the station to the stable zone without risk.

### 10- Quick fault clearing

It is required to protect the system from the external or internal faults so that a fast clearing for short circuits under emergency conditions may be a condition.

These ten items are very important to realize a good design and they all or some of them can give the general profile for the design. They may be a good tool for comparison and choice.

## 1-2 Elements of Design

The station may include more and more elements but we are going to discuss the most important between them.

### 1- Measuring Instruments

The measuring instruments are a main tool to work with a power system although a station may be appeared as an individual action inside. We need to measure the voltage, current, power, energy, power factor, transient performance and others. Therefore, a measuring toll will be necessary in spite of the HV and EHV levels presented in the station. The measurement can be fulfilled through the known current transformer (CT) for current in large values and voltage transformers (VT) for voltage. All other parameters could be deduced by these two fundamental values.

The characteristics and operation must be studied before applying the design process.

### 2- Protective Devices

On the other hand, the devices, working for the protection purpose as relaying, protective circuits and scheme will be benefit to act with the design.

### 3- System Characteristics

This means the operation planning, maintenance plan, points of connections to the network, importance of the Station inside the power system and its voltage level relative to the system.

## 1-3 Types of Stations

They can be classified as:

### 1- Door Style

It contains two basics types:

### 1- Indoor Style

This means that the station is installed inside a building and it is used up to 66 kV & even 110 kV level. It is suitable for P. S. and its elements. Requirements for such stations mainly are : (Control room; Boilers, Stores, Measuring devices, Workshop, Compressors, Pumping stations)

### 2- Outdoor Style

The installation is done in the Yard without buildings so that it is suitably normally for the voltage level of 66 kV and above. Although the HV is applicable for out door stations, sometimes it is implemented for 11 kV. It is suitable for sub stations.

### 2- Loading Style

The load capacity according to the load curve characteristics can be a vital subject. This load curve may be planned either statistically or specified to a certain

condition. This includes the number of loads, type and the performance of variation.
The load curve is a clear title for the design according to the concept of the station . This may be written as follows:

### a) Generating

It is necessary to determine the rated power of the station and the proposed power factor either planned or statistically. Also, number of units in the power station as well as its type: as nuclear, hydro or steam. Otherwise, the performance and the site of the station will be important factors. So, the place of connection to the network and the purpose of the station installation would be clear before the action of the design process and calculations.
The characteristics of generating a load either for a large scale or short may mean to a certain extend a meaning. Hence, the study of the load curves will be a positive factor in the design so that statistical presentation may be important.
Many types as nuclear, steam, gas, water, wind, solar, mass, hydro-electric. It may be of large capacity or small, multi voltage level or unity. Auxiliaries for a P. S. are: (Repair rooms, ventilation, offices, lighting, measuring, Fire alarming, elevators, control units, ...)

### b) Transforming

The sum of loading as a load curve at both sides of a transformer, and sequentially for all transformers will affect the distribution of loads according to the load curve. This means the best choice for loading during the 24 hours a day. It indicates the most suitable connection will depend on the load curves supplied by a station.
Them, a Sub Station is defined as the transformer station which
deals with the conversion of power from a voltage level to the other. It includes the possibility of voltage control or power compensation.

### c) Switching

The switching process induces a level of voltage over the nominal rated values. This means that the switching affect the system either circuit breakers or the elements of the station. Therefore, the contents of circuit breakers with the automation can be considered to prevent the high level induced as possible.

### d) Feeding

It depends on the shape of loading with respect to the load curve performance as given above with generators or transformers.

## 3- Elements of Design

The main items included in the design of a station are :
1- Single Line Diagram
2- Switch Boards
a- Power Board
b- Control Board
c- Protection Board
3- Circuit Breakers
4- Bus Bars
5- Measuring Instruments
6- Control Wiring
7- Grounding Systems

There are two types of grounding and earthing :
a) The grounding to neutral zero potential in the earth and this may be applied through :
i- Local
ii- Grid
b) The grounding above the conductors to protect the station and its elements against lightning strokes.
After that, station classification can be defined as :
1- Main Power Station
2- Auxiliary Generating Set Up Station
It is important to connect the renewal energy stations (Such as wind farms or solar stations) to the network. Such stations cannot act as a main P. S.
3- Standby Power Station
4- Transmission Set Up Station
5- Transmission Set Up / Set Down Station
6- Distribution Multi Service Step Down Station
7- Distribution Industrial Step Down Station
8- D C Distribution Station
9- Converting Station
It should be mentioned that practice defines some fundamental rules that are considered. Otherwise, the transmitted power is directly related to the transmission distance as it is given the Table 1-1. The list in the Table contains the surge impedance besides. It is seen that the Kelvin's law may not be needed because there many other factors takes a role in the design of a transmission system.

**Table 1-1: Transmitted Power**

| Voltage, (kV) | Surge Impedance of 400 Ω | Surge Impedance of 300-315 Ω | Surge Impedance of 250-275 Ω | Max. Transmitted, MW | Max. Distance of Transmission, km |
|---|---|---|---|---|---|
| 35 | - | - | - | - | 50-60 |
| 110 | 30 | - | - | 25-50 | 50-150 |
| 220 | 120 | 160 | - | 110-200 | 150-250 |
| 330 | 270 | 350 | - | 300-400 | 200-300 |
| 400 | 400 | 500 | 580 | 500-700 | 600-1000 |
| 500 | 600 | | 900 | 700-900 | 800-1200 |
| 750 | | | 2100 | 1800-2200 | 1200-2000 |

# Chapter II
## Bus Bar Systems

**The of Bus Bar means the connection of electrical terminals of wires and cables to be joined together in the shape of a node so that it is practically cannot be implemented as a point. Consequentially, the electric concept of Bus Bar (BB) is a point ( node) while it is practically not a point.**

**Bus Bar = Node (2-1)**

**Table 2-1 BB shapes and their moment of impedance.**

| Poles geometry of BB | Moment of Impedance |
|---|---|
| a | |
| b | $0.167\ b\ h^2$ |
| b, h | $1.44\ h\ b^2$ |
| | $3.3\ h\ b^2$ |
| d | $0.1\ d^3$ |
| D | $0.1\ (D^4 - d)/D$ |
| b, b, b | $0.333\ b\ h^2$ |

## 2-1 Theoretical Items

**Since it is concluded that the BB is a point from the point of electricity view, we can treat it according to the Kirchhoff's law as:**

$$\Sigma I_{in} = \Sigma I_{out} \qquad (2\text{-}2)$$

**This also, means that BB is a conductor, which shape may be different in many types. Various shapes are listed in Table 2-1 where the moment of impedance for each shape is formulated mathematically.**

**Also, the effect of bundling of the strands of the BB can be more clear from Fig. 2-1 where double and triple bundled conductors are illustrated for the moment variation with respect to the ratio of width to length.**

### 1- Operation Performance

A BB expresses well about all connections inside so that it can be a mirror for a station at all. This indicates that this BB is an important element in the design of a station and then, it should be treated on a high level of study. Hence, a detail study may be explained in the following points.

### a) Main Bus

This BB is considered a main due to its basic style in the operation processes although it is a simple one. Nevertheless, BB as a main node in a station appears as a week point from the reliability point of view. So, it will be an important idea to investigate well this item when we find the normal shape of a BB in its simple form (Fig. 2-2). The shown main BB indicates the importance of its role in the electric circuit in the power system.

It is shown that all lines and elements of the electric system are connected to the main bus directly through a switch but with increasing the power the isolating switch cannot withstand against the spark mechanism during short circuit cleared. This increases the connection as given in Fig. 2-3 using a fuse to protect the circuit from the short circuit current. It is noticed that the switch is still presented in the connection for the reliability of operation (ON/OFF) in the normal conditions.

Later with the increase of power feeding the consumers, the circuit breakers (CB) were used besides the presented fuses (fig.2-4) but with the advantages of these breakers the system becomes only with CB as in Fig. 2-5 specially for HV levels. This final shape for the main BB will be modified in the next explaining through this chapter.

### b) Auxiliary Bus

Applying the system of main BB some problems were appeared such as the need for cleaning or maintenance or others but without the interruption of the power supply. Thus, a new thought must be introduced besides the presented one (Fig. 2-6). This leads to the use of a standby BB with the main so that the cost of BB may be duplicated. The new auxiliary BB is a good solution for this problem in spite of its idle presence in the system. The reliability of the system is raised and connections between both main and auxiliary BB will be increased later.

### c) Mixed Bus

After that the appearance of auxiliary BB, modified connections and uses are introduced. This mixing for the purpose or the utilization or the need is always going on and still now in such a dynamic condition. It depends on the voltage level or capacity, critical operation importance of the supply or the load or others. Then a more detailed study may be required in the next point.

## 2-2 Classification

The classification of BB depends mainly on the voltage level, i. e. on the power where increasing power going to raising the voltage. This is needed to reduce the rupture capacity of CB in the network which means less cost for the same action. Hence, the different types of BB may be tailored as below.

### 1- Single Bus Bar

The single BB system may be classified as follows:

### A) Simple Type

This contains some simple types of BB :

### 1- Single Bus with switches

It is suitable for distribution at low individual loads that permit the interruption of the current. In this case the switches are low price and low power (Fig. 2-2).

### 2- Single Bus with fused switches

It is suitable for machines and devices on the distribution voltage level in order to protect the equipment connected to the network (Fig. 2-3).

### 3- Single Bus with CB

It is suitable for all types of loads in the low voltage level ((Fig. 2-4) and in this situation a mixing scheme may be used (Fig. 2-5).

### B) Ring Bus

It is a more reliable type since it leaves the system as a double side power feeding (Fig. 2-7). It may cover the system of important loads but it has a disadvantage as the circulating current if the loop (ring) is closed, It also, may be given in different shapes as in Fig. 2-8 for simple (a) as above (fig. 2-7) or for doubling the cutting in the ring to present a direct two passes (b) or to increase another one ( c ). There are also, other shapes for the ring type of BB such as the triangle or diagonal concept as given in Fig. 2-8 (d, e) or square style as in (f)

### c) Bridging BB

There many connections that can be considered as linked or bridged BB as:

### 1- Simple single link BB

It uses a connection to give the facility to feed a load from another near supply as shown in Fig. 2-9. It permits the link connection from single I. L. with or without a CB as given in the figure.

### 2- Double dis-connector Single link BB

It permits the link connection from two I. L. with or without a CB as given in the figure (Fig. 2-10).

### 3- I. L. / CB Linked BB

This scheme depends on the system of double way where one takes the CB with another with I. L.( Fig. 2-11).

### 4- CB Double link BB

Here we use the CB in the branches that linking both sides (Fig. 2-12).

### 5- Different Styles

This means various possible connections for different loads according to the type of load as in Fig. 2-13.

### d) Practical Schemes

They are many but we can present the most common as: double section (Fig. 2-14), triple section (Fig. 2-15), multi section (Fig. 2-16), star principle (Fig. 2-17)

### 2- Double BB System

Now, it is necessary to illustrate the meaning of double BB and thus, the next sequence of items may be helpful.

### a) Spare Bus:

It has been defined above the expression of spare bus or auxiliary BB (Fig. 2- 6) and other two shapes can be added as given in Fig. 2- 18: (i. For Low Power, ii. For Low Power).

This system contains two buses instead of one as given in Fig. 2 –19 where two CB are used in the circuit (each/BB). This facilitate the process of ON/OFF individually for each BB (main or spare) while double BB single CB may be used instead as shown in Fig. 2-20.

### b) Bus Coupler

It is a new CB which must be added to the scheme of single BB system to couple the spare BB together with the main one as a double BB system. It should be followed by an isolating link from both sides ( Fig. 2-21). Thus, the single CB/Double BB can be used correctly with the insurance of continuous supply.

### c) Circuit Breaker Savings

Referring to Fig. 2-20 and Fig. 2-21, we can find that for a circuit connected to the double BB system one CB is saved while it is added as a bus coupler. This means no saving in the number of CB in the circuit. Contrary, if the circuit contains 10 lines connected to the BB, we will save 10 CB from these lines. Although a bus coupler should be used, a saved number of CB will be 10 – 1 = 9 CB due to the use of bus coupler (BC). More connection to BB means increased number of saved CB in the system, and so, lowering the cost level for the design.

Firstly, double BB has been applied for standby operation when cleaning or maintenance. With the growth of the power the need for the continuous operation of the spare bus is increased so that it became as two individual stations as single BB. This was a good solution with the raising in the short circuit level at the BB zone.

### 3- Triple BB System

It is known that the growth of generated and transmitted powers is going forward. This leads us to find that the double BB system cannot withstand with the new growth so that a third bus may be necessary, This means the triple BB system (Fig. 2- 22). Also, it is required for P. S. as a synchronized BB as shown in Fig. 2-23.

### 4- Group Bus System

The grouping BB system may be used for feeders as the shape of H (Fig. 2-24) to present a more reliable connection or as a multi-feeder bus system (Fig. 2-25). The grouping BB systems may be defined as a system of connection for a typical types of groups as in Fig 2-26 for the typical grouped radial style as well as the grouped typical transformer connections as given in Fig. 27. This last group contain four different typical single line diagrams while others may be defined as:

1- Block group type which appears to suitable for power stations, specially the hydro stations ( Fig. 2-28).

2- Transformer sharing group of Fig. 2-29 that is applied to the power stations including many numbers of units of solidly connected performance.

3- Reactor grouping type (Fig. 2-30) and it suits the distribution network for feeders with high short circuit level.

4- Grouped transformer style of Fig. 2-31 can be easy used EHV and UHV levels.

5- Double way BB system (Fig. 2-32) where a power station includes a multi way of supply and multi way of loads, i. e. in many directions for loading.

## 2-3 Sectionalization

As said before for the double or triple BB system and the need for the BC as a tool for the coupling between both BB (main and spare) we repeat the same but with the sectionalization concept. Fig. 2-33 shows the single BB style but it has been divided into a number of sections. This is given again for the double BB system (Fig. 2-34) where the double CB breaker is taken as the base for the drawing.

Advantages of Sectionalizing may be indicated as : Limitation of S. C. current – Reduction of mechanical forces on buses & windings – Isolate zone of faults – Permit the back up protection against the failure of a breaker at a feeder. Also, it can Isolate Each Gen. & section –a Bus Tie is normally opened .

It is given for the triple BB system in Fig. 2-35.

### a) Bus Tie

The bus tie (BT) is similar to the BC because it isolates each section of BB individually. It seen in Fig. 2- 33 , 2- 34 and 2-35 where single, double or even triple BB system is applied. Then, on such bases the ring sectionalized BB system can be illustrated in Fig. 2- 36. The synchronizing tie and bus are shown in (b).

### b) Synchronizing BB

It is an important style for the P. S. in general because it is a main concept fo the connection of generators to the network (Fig. 2-36 for the synchronizing tie and bus as well as (2-37).

It is necessary to put the main schemes related to the sectionalization subject after the presentation of the synchronizing BB because it was the actual entrance for the section style in the BB. These BB systems may be tailored in the form:

### 1- Simple node BB

This has been explained before and illustrated well.

### 2- Solid node BB

This type of BB has been in duty for a long time as it is working stable in all stations. Such a system may be specified as:

a- Solidly Connected BB as in Fig. 2-38 where the BB is connected directly to the alternator unit. The outgoing lines and feeders or transformers should have the CB with BB while the units are connected directly without any CB. The disadvantage in this case will be the independence on the loads.

b- Solid line / BB connection (Fig. 2-39) where the CB presence is transferred to the units mainly on contrary to the last one. It canceled the disadvantage above.

### 3- Multi path BB:

The most suitable solution for the reliability level in the operation condition may be the application of this concept. This may be classified in the form:

a- Single input / output style (Fig. 2-40) and it is convenient to the P. S.

b- Single input double output (Fig. 2-41) where for each input line or supply there are two outgoing lines as illustrated in the figure.

c- Multi-node BB: This type of BB is more expensive but it works at a high degree of reliability as shown in Fig. 2-42

d- The 3/2 node BB : It means that for each two input supply branch connected to the BB there are three branches outgoing from it (See Fig. 2-43).

e) The 4/2 node BB : It represents the input of two ingoing lines while the out going is 4 lines so that it is suitable for the connecting stations inside the transmission system. It will be illustrated later.

### 4- Typical Schemes:

They may be a lot of connections but we put a sample for illustration as the drawing in Fig. 2-44 for P. S. and in Fig. 2-45 for mainly S. S. Also Fig. 2-46 presents a typical connection for a distribution station. It is shown that both 3 and a 4 winging transformers are applied in the system. The given schemes are presented to complete the idea of changing the performance of BB although it may be believed that the BB is a simple or even very simple subject.

## 2- Voltage Level

The BB could be specified according to the level of its voltage because the growth of the power takes the BB to a wide change in both use and purpose. Then, the BB can be tailored according to the voltage level in the following characteristics:

### a) Single voltage level

This system is the normal which is used always in the distribution network and so, it is possible to pt such a system in either single , double or triple BB. All the above circuits represents this condition although other types for P. S. can be approved as given in Fig. 2-47. This is called as the single voltage level for the 110 kV P. S. where all units are connected to the main BB.

### b) Double voltage level

In The presented case the voltage of BB may be different at the same side as given in Fig. 2-48 where a three winding auto-transformer is installed between the two sections of a single bus at different voltages of 110 and 220 kV. This may increase the reliability factor due to the different level of voltages either against faults or the stable balance in the distribution of operation action.

### c) Multi voltage level

On the basis of the double voltage level it is expanded to be more than two voltage and Fig. 2-49 brings the circuit diagram for a triple voltage BB (110 / 220 / 500 kV). It is given to the P. S. with a lot of generators connected to the three voltages BB increasing the possibility of stability and we see the auto-transformers are connected as a tie tool between sections of the BB.

Advanced connection is drawn in Fig. 2-50 where isolated BB sections are put but an auto-transformer connection between both isolated sections of the BB is decided in two points (not one) Therefore, the sectionalization concept leads the subject of BB more valuable and interesting. This tie connection by transformer windings may expanded to tie more than one section to a certain one and then, a multi connected section BB can be utilized as the interconnected network principle. Thus, a multi voltage level sectionalized BB with a great benefits may be introduced.

## 3- Short Circuit Performance

The BB style must help us to protect the system against faults as well as the wrong operation. It must protect the operation according to the automatic interlock principle although the operators are specialists in the field. Also, it protect to a extend the faults through the limitation of the short circuit current by introducing a connection to help. This may be applied depending on the following items:

### a) Reactor Insertion

Since the active resistive impedance leads to an active power loss, the concept of reactive impedance has been activated in such a manner. The rector insertion may be the best solution for this case due to the possibility of angle control to put the voltage at both sides of the reactor is the same. Thus, a single level of voltage can be implemented and a limitation for the short circuit current is available. On the other hand the reactor may be used for the compensation purpose with lon lines where a large capacitive power will be appeared. So, a tailored connections would be presented below.

### 1- Series reactors

It is used for the limitation of short circuit currents in the circuit and they may be installed as:

i- Bus reactor ( Fig. 2-51)
ii-Feeder reactor ( Fig. 2-52)
iii- Generator reactor (Fig. 2-53)
iv- Transformer reactor ( Fig. 2-54) where it suitable for the Large P. S. and for the Parallel operation of generators.

v- Neutral reactor ( Fig. 2-55)
vi- Generator reactors for synchronous bus where is convenient for the voltage regulation and control in general ( Fig. 2-56).
vii- Double reactor type (Fig. 2-57)
viii- Regulator insertion concept (Fig. 2-58).

## Shunt Reactors:

It is required to use either a resistance or a reactor for grounding and the most common is the neutral reactor as given before. Shunt reactors may be used for bus with the double winging generators (heavy power) as shown in Fig. 2-59 it may be installed at the end of long distance transmission lines For reactive power compensation (Fig. 2-60)

### b) Transformer Utilization

This has been illustrated before as in Fig. 2-44, 2-46 and 2-50. They may be used to tie or to limit the short circuit current to a certain extend or to equalize the stable operation of a scheme.

### 4- Special Conditions

a special case may be needed for a certain condition and the main connections relative to the BB types may be shortly indicated as:

### a) Bus Coupler / Bus Tie Combination

It is important to treat the system configuration in order to find the best solution including the technical level as well as the price and the cost in general. Here, both BT and BC are introduced and defined so that the process of design for a BB system should contain both of them for large power scale, Consequentially, the engineering view for these breakers as the aim from them must be modified. Therefore, the BC is an idle breaker for a long time while the BT is an active always. So, the combination between both BT and BC may be a good idea to reduce the cost specially with EHV and UHV levels. The engineering concept for the process of their combination has been developed as in Fig. 2-61 for the BC in steps, for BT (Fig. 2-62) but it is shown in Fig. 2-63 for the combination procedure.

## b) Basic Path Connection

1- Outgoing and ingoing BB
Whatever, a basic scheme for different path connection is presented in Fig. 2-64 (a and b) in both directions ( Out going or in going ). The schemes are given for the generator connections with the sectionalized BB system.
2- Sectionalized Double BB with single bus operation as shown in Fig. 2-65 by its basic classic style
3- Half sectionalized BB with reactor insertion is drawn in Fig. 2- 66.
4- Double CB Concept is given in Fig. 2-67 but
5- The symmetrical sectionalized BB is given in Fig. 2-68.
6- The generator normal connection is shown in Fig. 2-69
7- Multi voltage level BB is drawn in Fig. 2- 70.
8- Isolated section double BB is given in Fig. 2-71
9- Triple sectionalized BB in Fig. 2-72.
10- Sectionalized Ring BB
They may be shortly as a main type of them in the following shapes:
a- Simple Ring BB (Fig. 2-73)
b- Double Ring BB (Fig. 2-74)
c- Triple Ring BB (Fig. 2-75)
d- Generating Ring BB (Fig. 2-76 a, b)

**11- Sectionalized Synchronous BB**

**Since the sectionalization has the advantages:**

**i- Limitation of short circuit current**

**ii- Reduction of mechanical forces on buses and winding**

**iii- It permits the back up protection against the failure of a breaker at a feeder.**

**This leads us o use it widely and so for the synchronous BB that may be tailored as:**

**a- Generating Station BB (Fig. 2-77)**

**b- Double BB with the synchronous bus with the advantages of improving the performance of sequential out of step for the units connected to (Fig. 2-78).**

**c- Ring Synchronous BB (Fig. 2-79).**

**d- Semi-isolated BB for large power stations (Fig. 2-80).**

**e- Half Sectionalized BB (Fig. 2-81).**

**f- Block type with reactors (Fig. 2-82).**

**g- Central Controller Use (Fig. 2-83).**

**h- Mixed Ring BB (Fig. 2-84).**

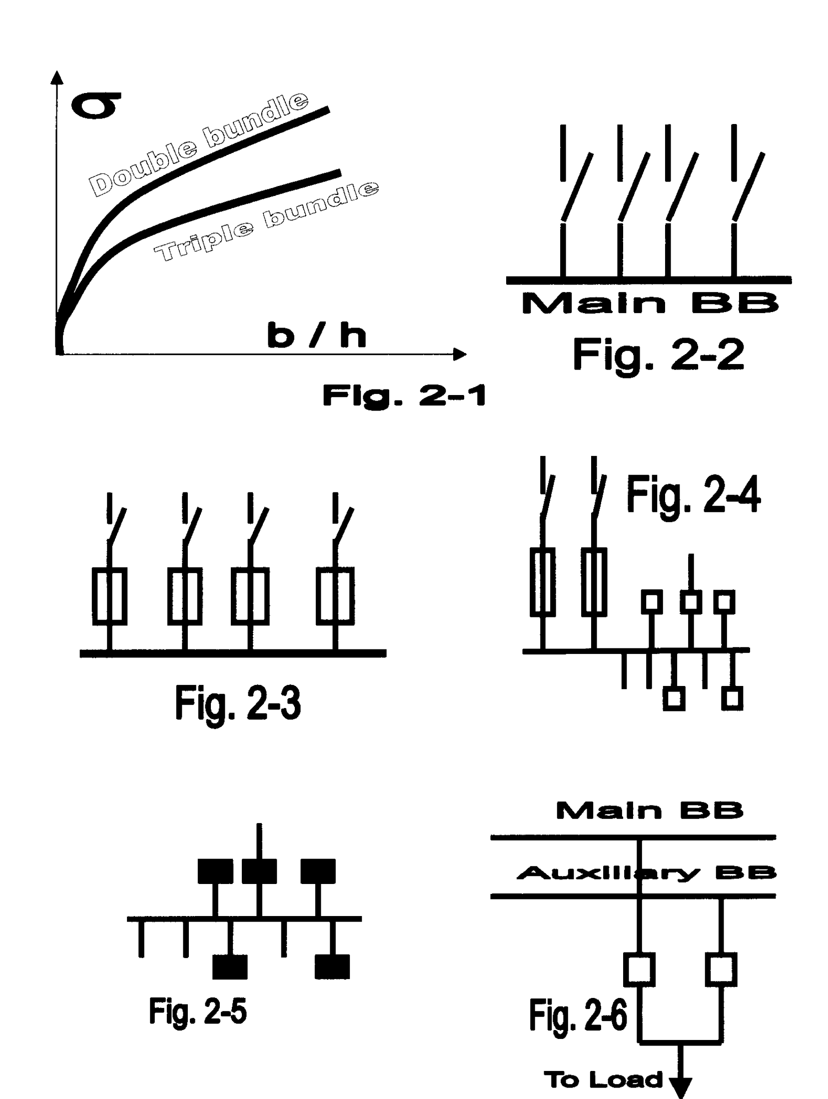



Fig. 2-1

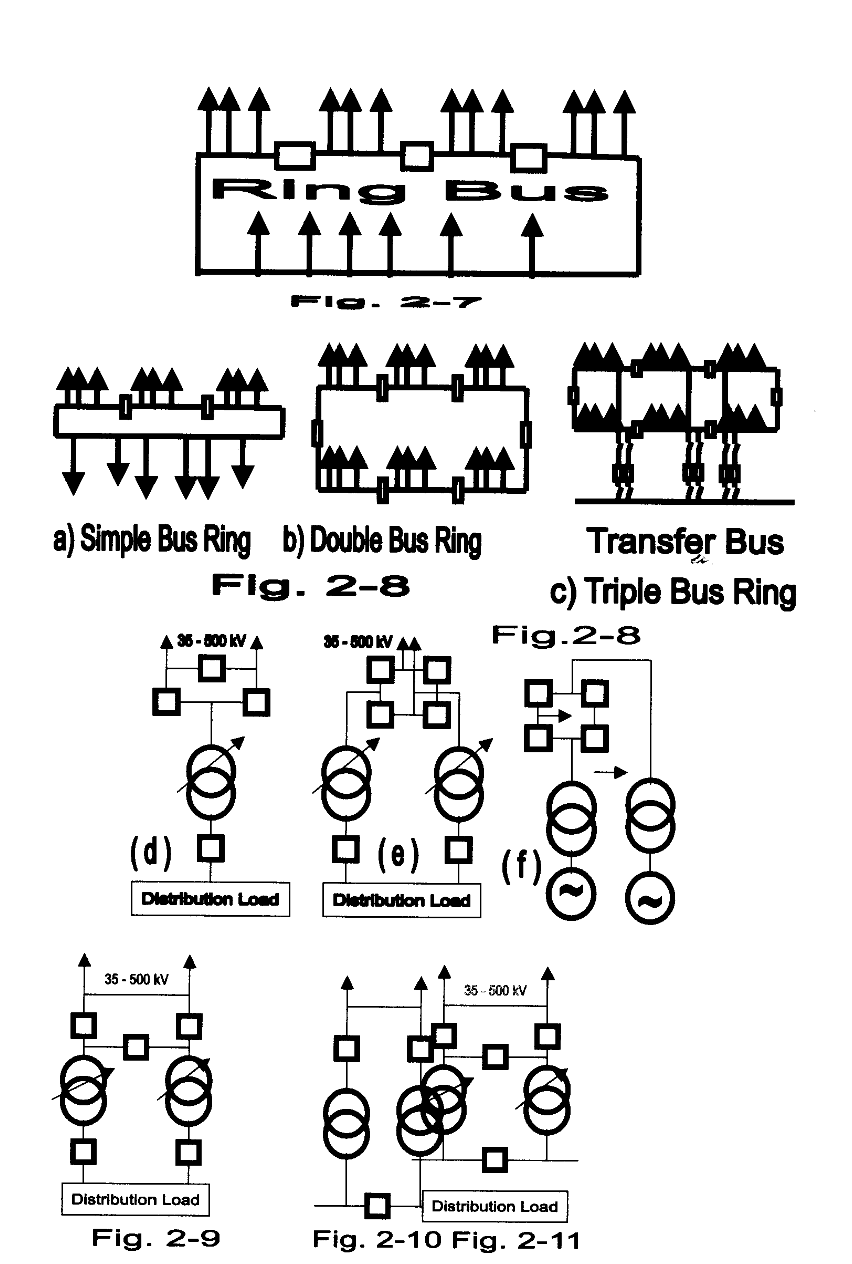
Fig. 2-2

Fig. 2-3

Fig. 2-4

Fig. 2-5

Fig. 2-6


Ring Bus
Fig. 2-7
a) Simple Bus Ring
b) Double Bus Ring
Transfer Bus
Fig. 2-8
c) Triple Bus Ring
Fig.2-8
35 - 500 kV
35 - 500 kV
(d)
(e)
(f)
Distribution Load
Distribution Load
35 - 500 kV
35 - 500 kV
Distribution Load
Distribution Load
Fig. 2-9
Fig. 2-10 Fig. 2-11

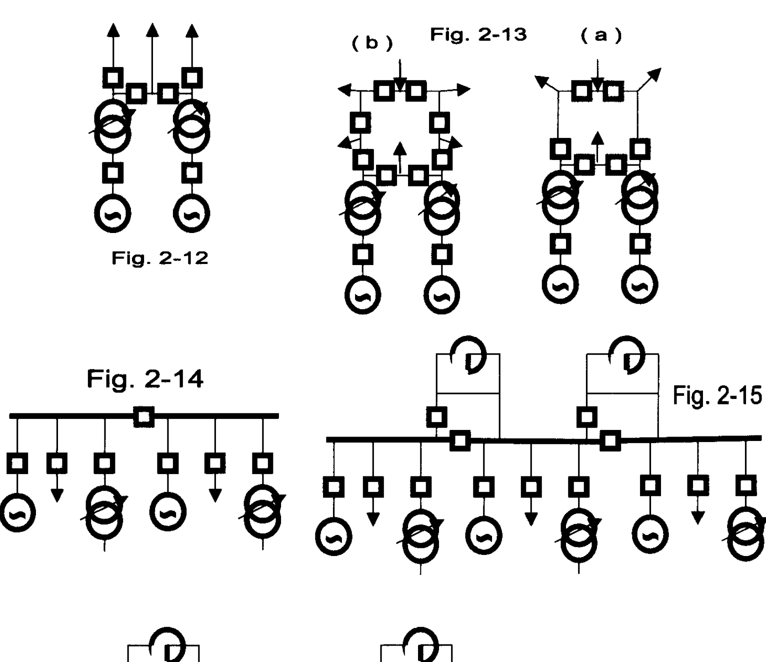



Fig. 2-12

Fig. 2-13

Fig. 2-14

Fig. 2-15

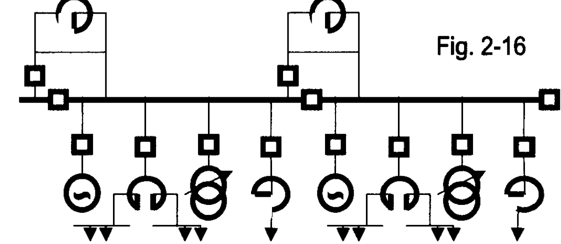


Fig. 2-16

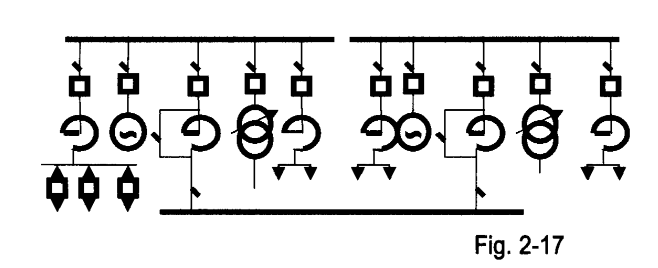


Fig. 2-17

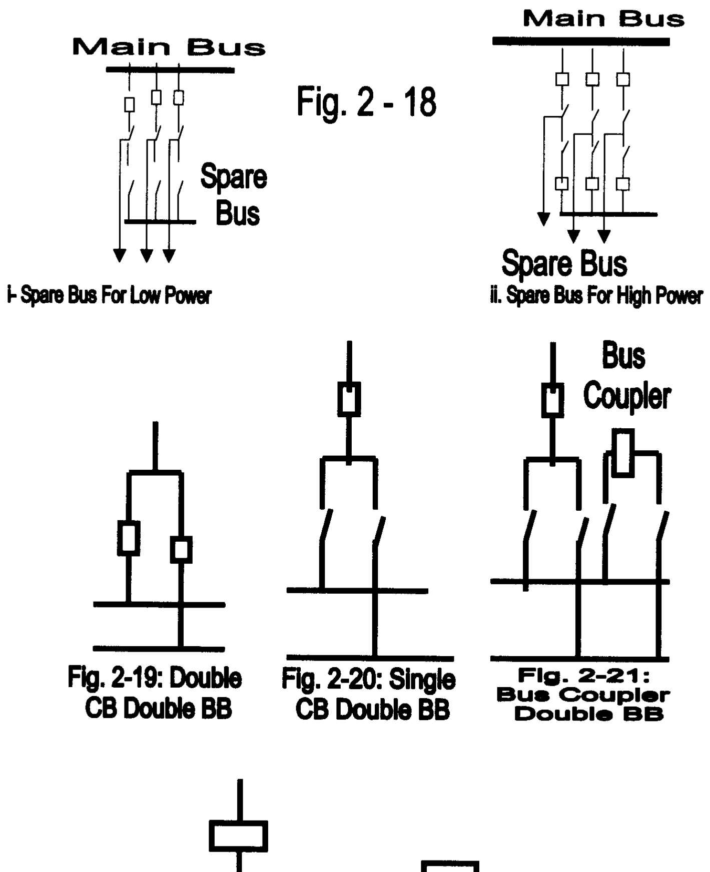



Fig. 2 - 18

i- Spare Bus For Low Power

ii. Spare Bus For High Power

Fig. 2-19: Double CB Double BB

Fig. 2-20: Single CB Double BB

Fig. 2-21: Bus Coupler Double BB

Fig. 2-22

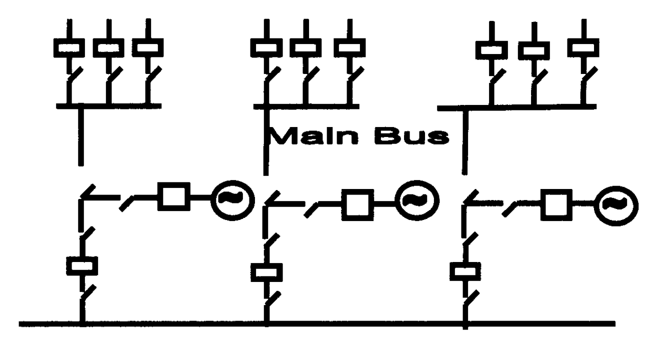



Fig. 2-23: Synchronizing Bus

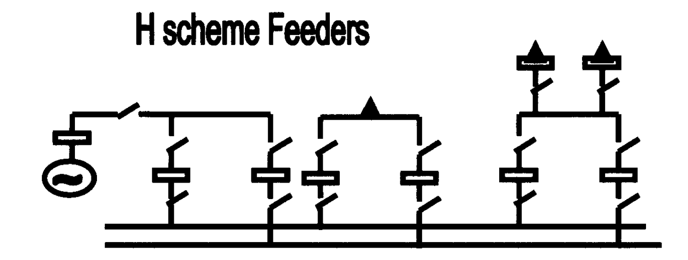



Fig. 2-24: H scheme Bus System

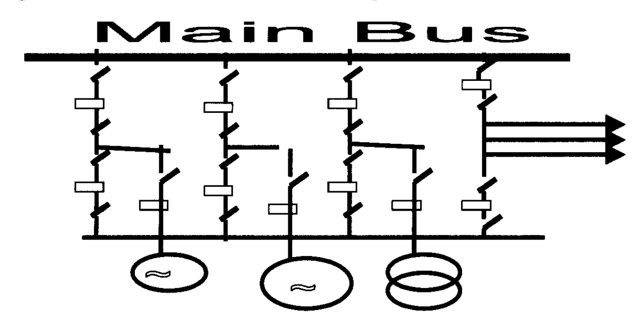



Fig. 2-25: Multi-feeder
bus System

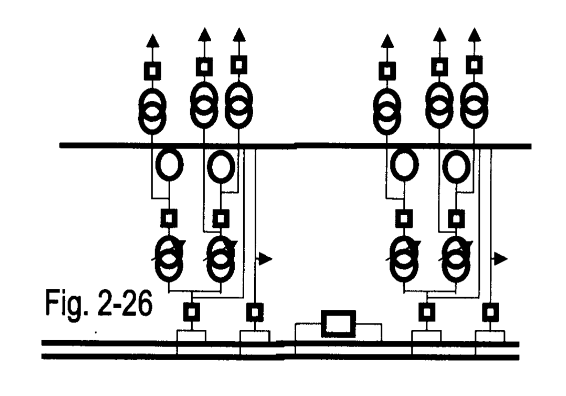


Fig. 2-26

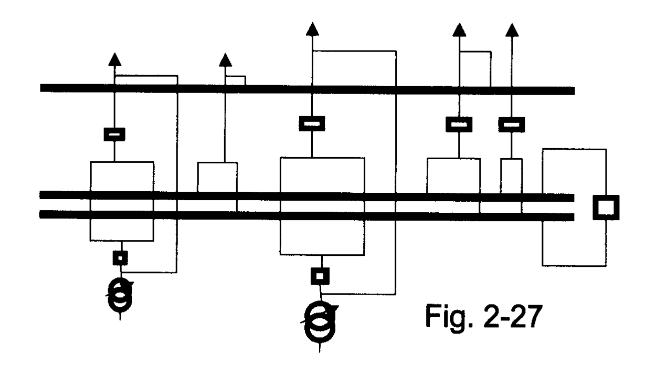


Fig. 2-27

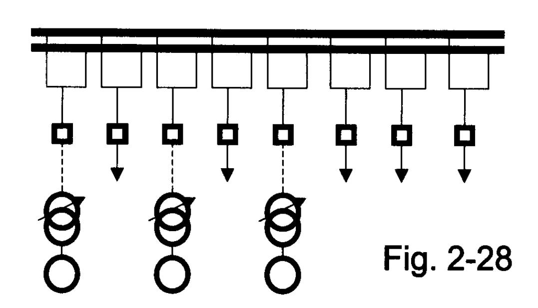


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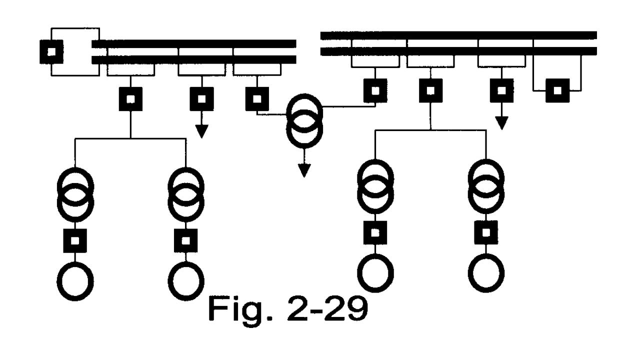


Fig. 2-29

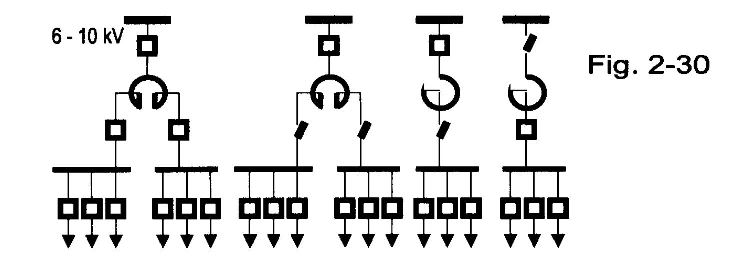



Fig. 2-30

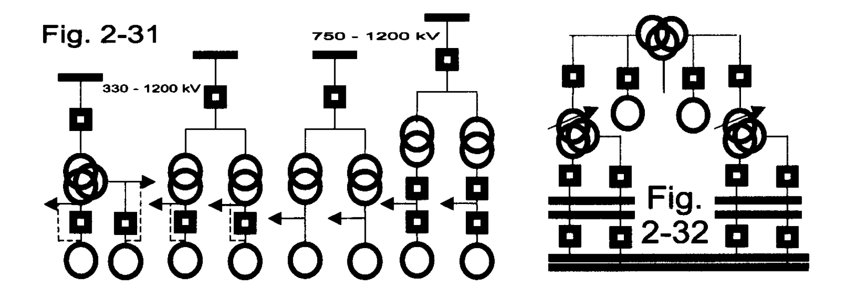



Fig. 2-31

Fig. 2-32

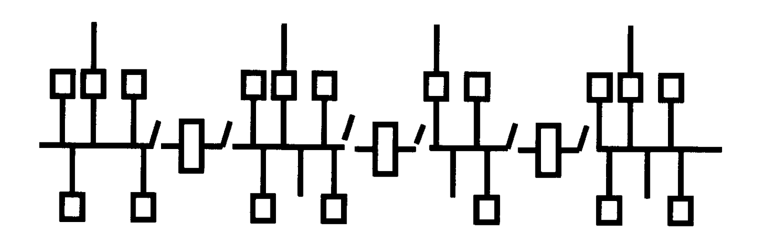


Fig. 2-33: Sectionalized Single Bus

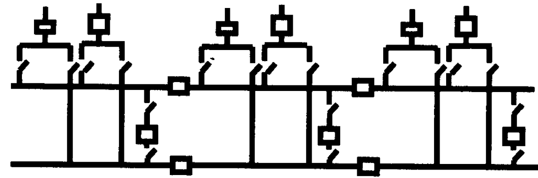
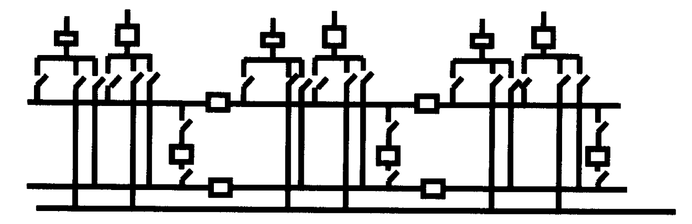


Fig. 2-34: Sectionalized Double Bus Bar with single bus operation

Fig. 2-35: Sectionalized Triple Bus Bar



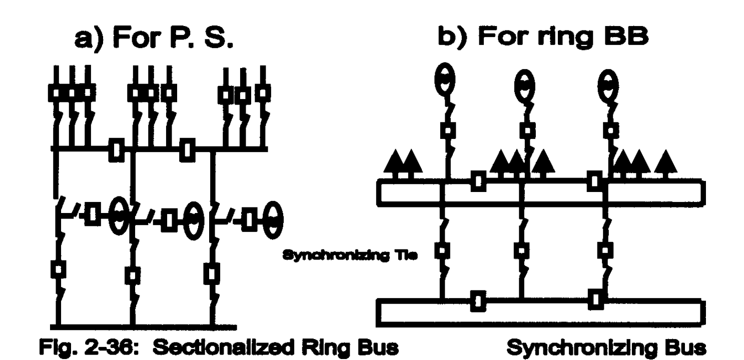



Fig. 2-36: Sectionalized Ring Bus

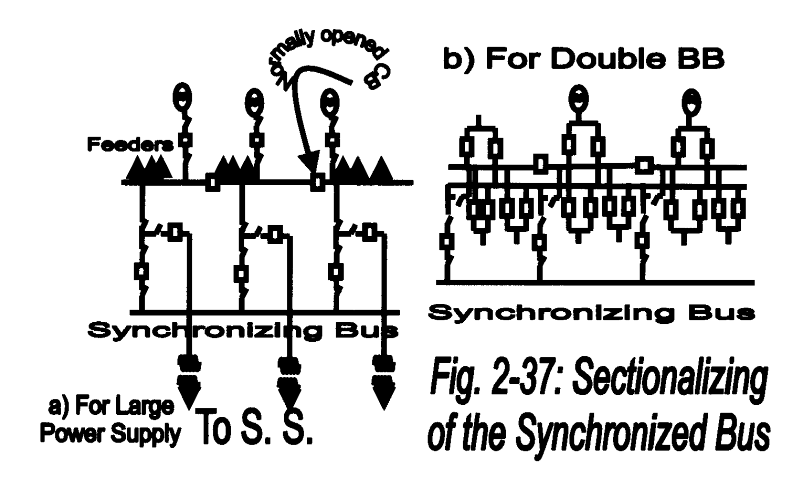



*Fig. 2-37: Sectionalizing of the Synchronized Bus*

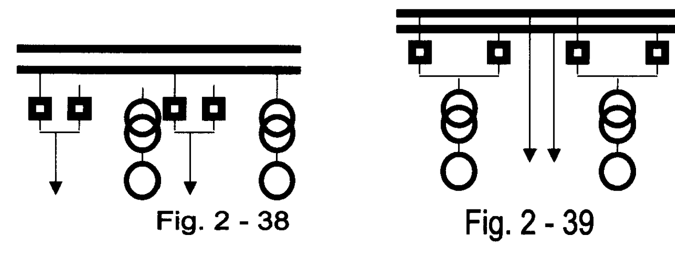


Fig. 2 - 38

Fig. 2 - 39

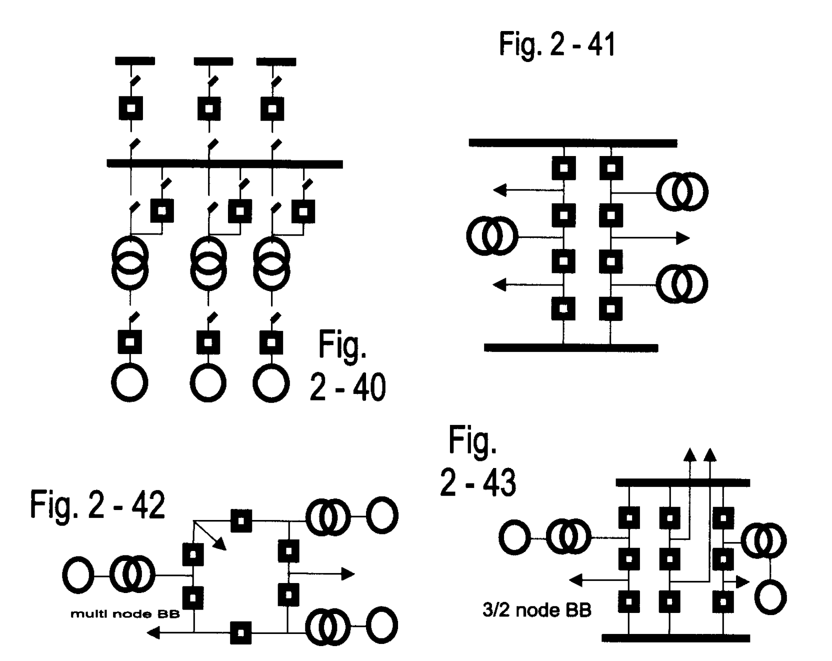
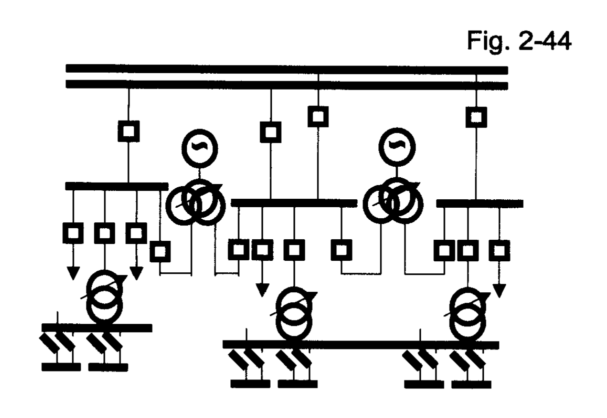


Fig. 2 - 40

Fig. 2 - 41

Fig. 2 - 42

Fig. 2 - 43


Fig. 2-44

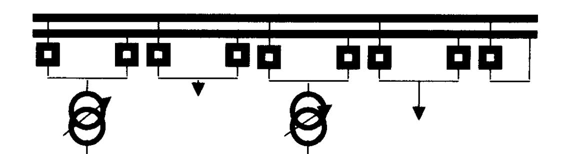


Fig. 2 - 45
typical schemes

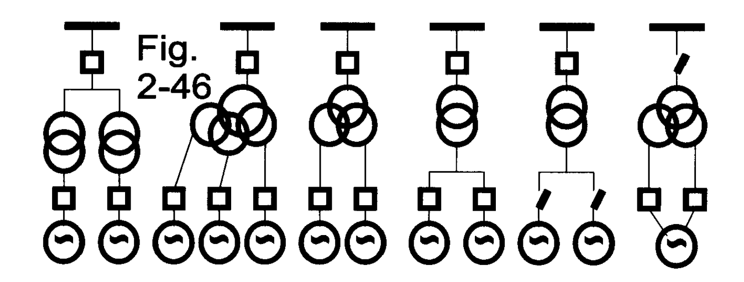


Fig. 2-46

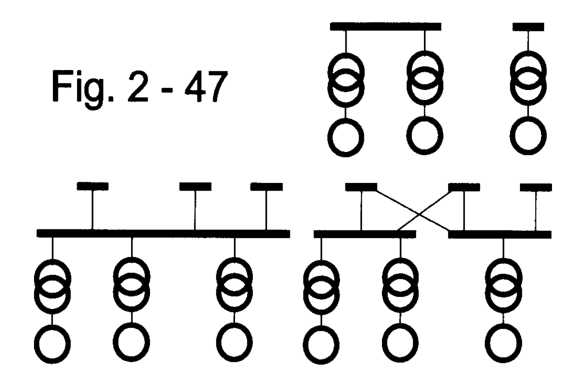


Fig. 2 - 47

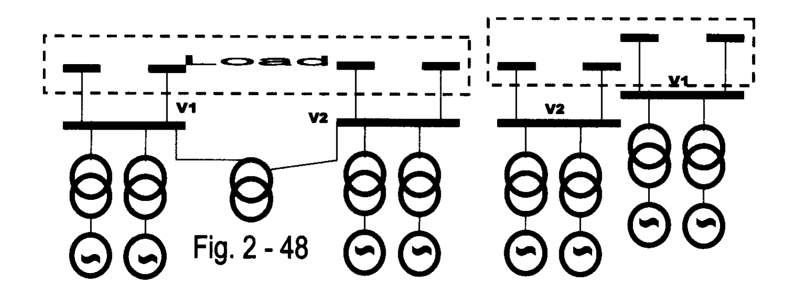



Fig. 2 - 48

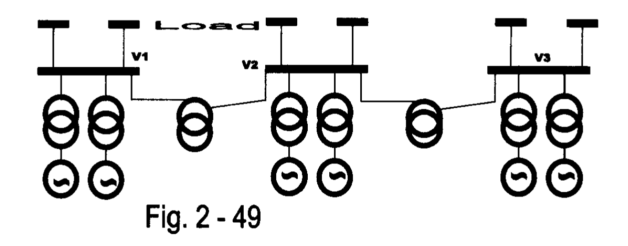
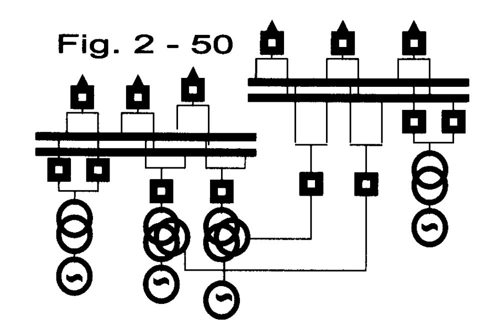
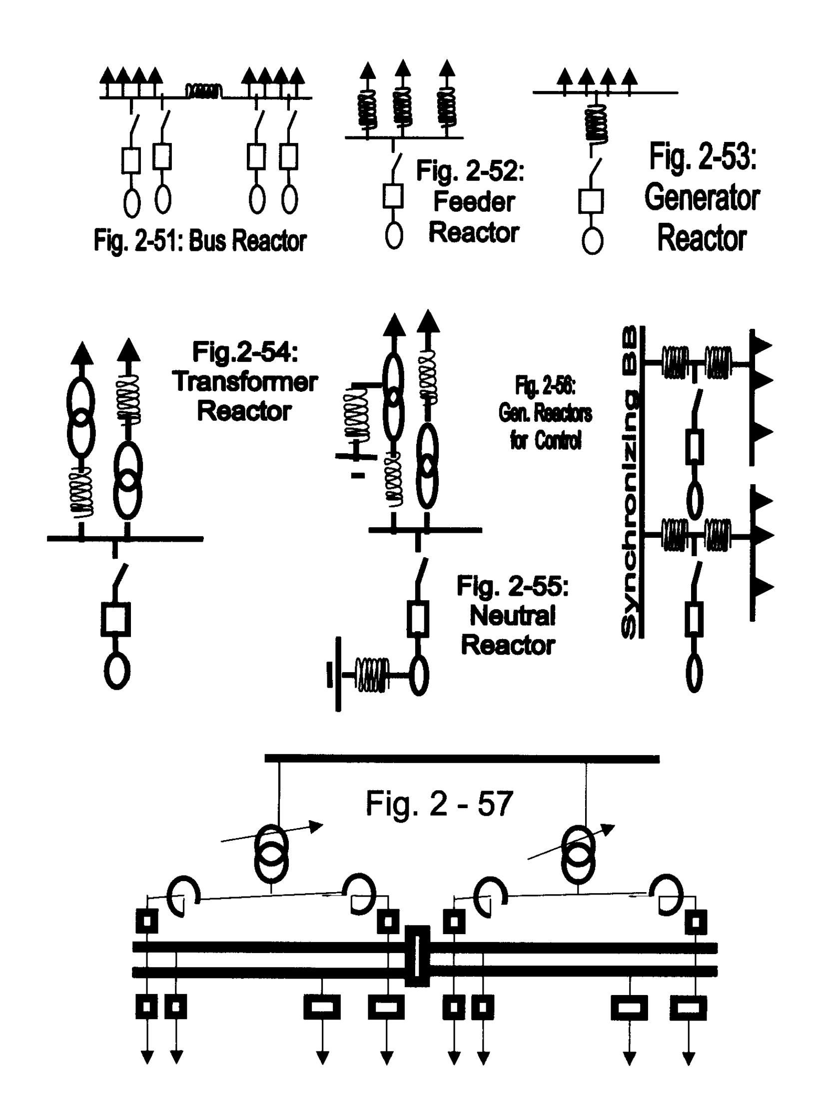



Fig. 2 - 49

Fig. 2 - 50




Fig. 2-51: Bus Reactor
Fig. 2-52: Feeder Reactor
Fig. 2-53: Generator Reactor
Fig.2-54: Transformer Reactor
Fig. 2-56: Gen. Reactors for Control
Synchronizing BB
Fig. 2-55: Neutral Reactor
Fig. 2 - 57

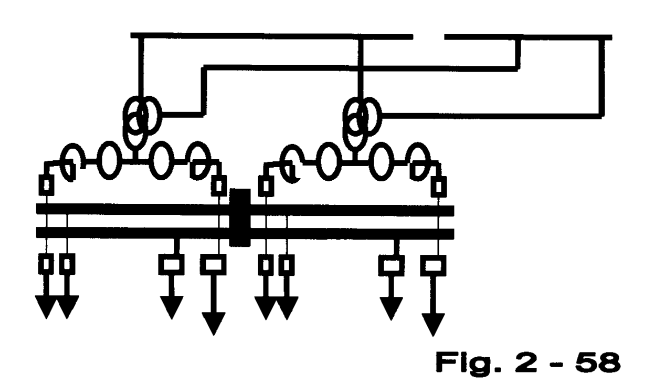


Fig. 2 - 58

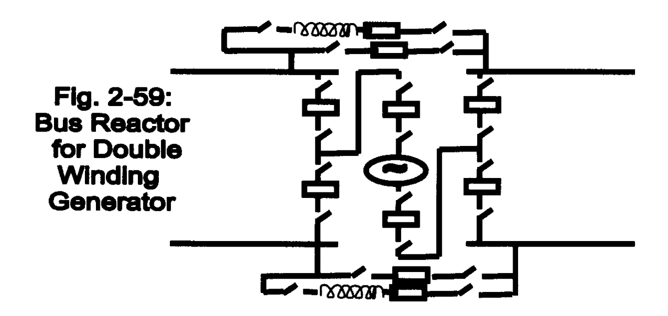


Fig. 2-59: Bus Reactor for Double Winding Generator

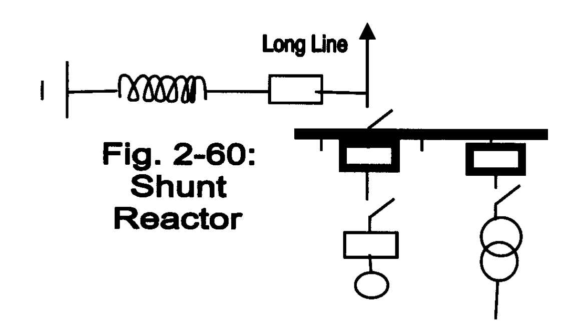



Fig. 2-60: Shunt Reactor

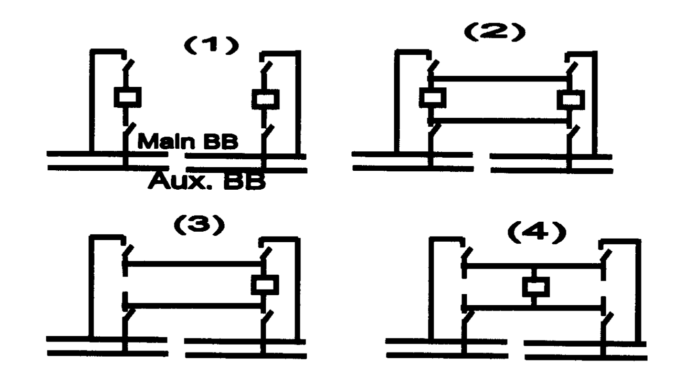



Fig. 2-61: BC Combination

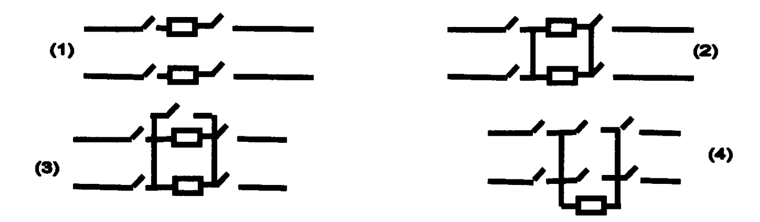



Fig. 2-62: BT Combination

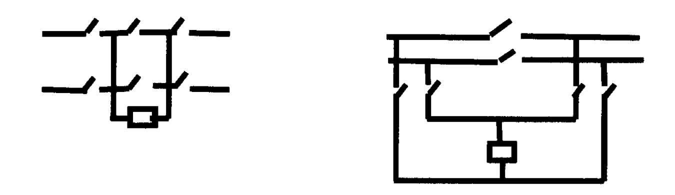
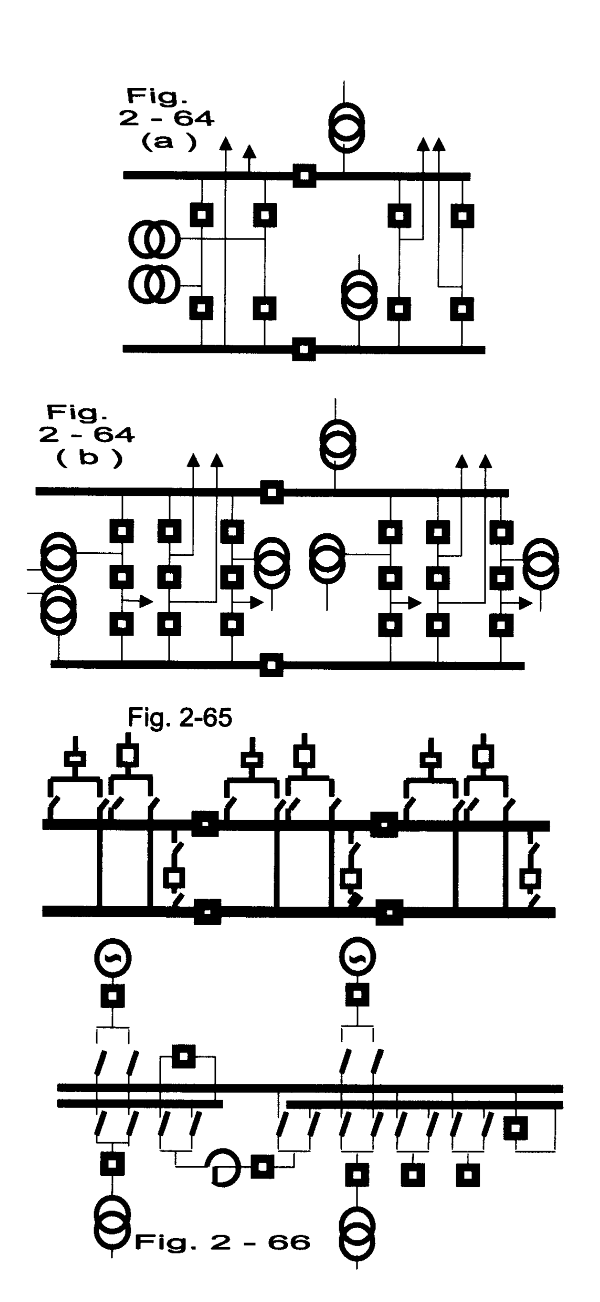


Fig. 2-63: BC / BT Combination


Fig. 2 - 64 (a)
Fig. 2 - 64 (b)
Fig. 2-65
Fig. 2 - 66

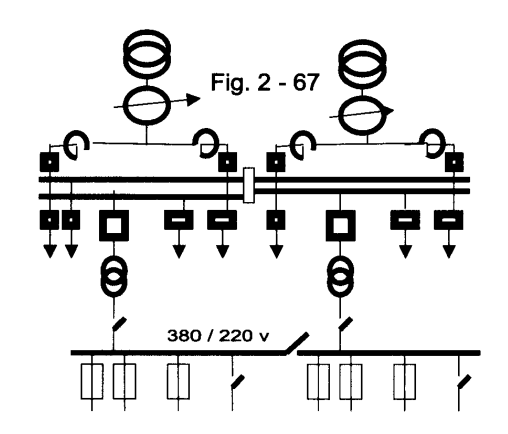
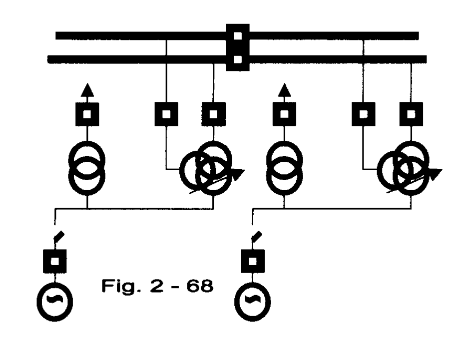


Fig. 2 - 67


Fig. 2 - 68

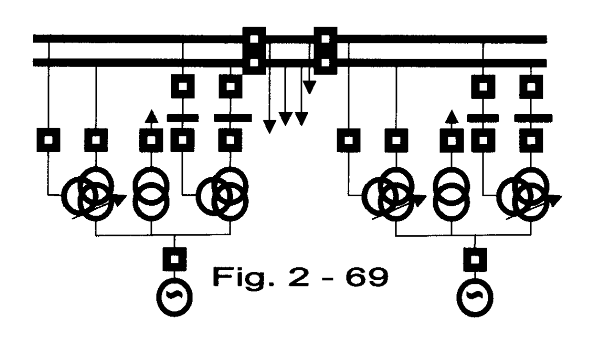
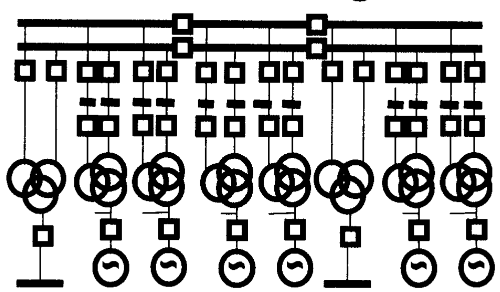

Fig. 2 - 69

Fig. 2 - 70 multi voltage level



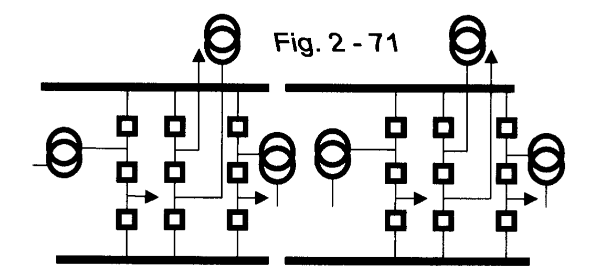


Fig. 2 - 71

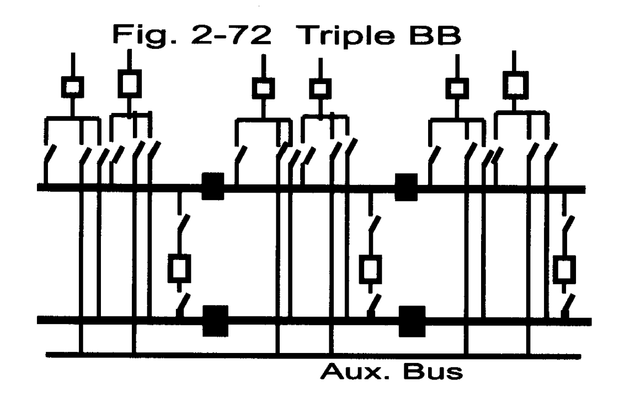
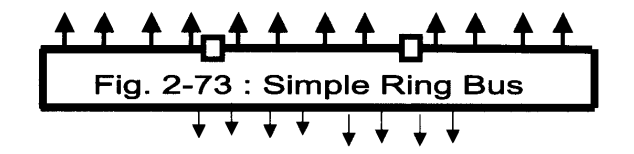



Fig. 2-72 Triple BB


Fig. 2-73 : Simple Ring Bus

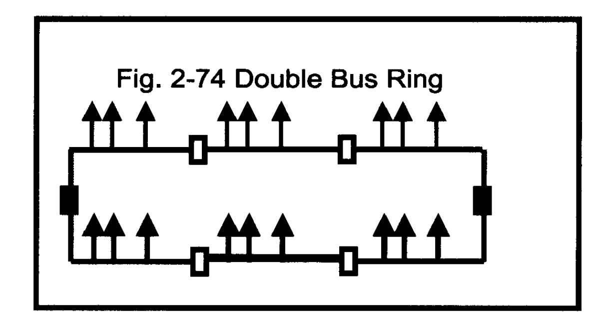
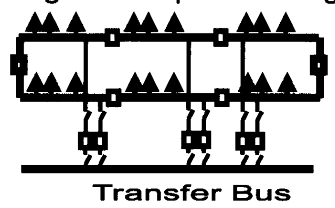
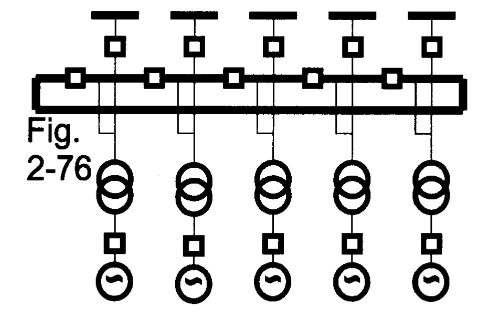

Fig. 2-74 Double Bus Ring

Fig. 2-75 Triple Bus Ring





Fig. 2-76

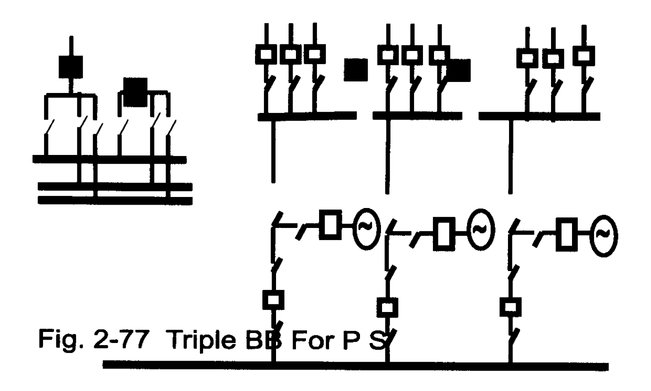


Fig. 2-77 Triple BB For P S

Fig. 2-78 Sectionalizing of Double BB

Synchrounising BB For Large P S

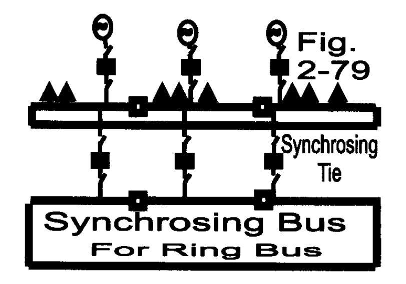



Fig. 2-79

Fig. 2-80 Sectionalizing the Synchronizing BB

normally opened BT

Synchrounising BB For Large P S

To SS

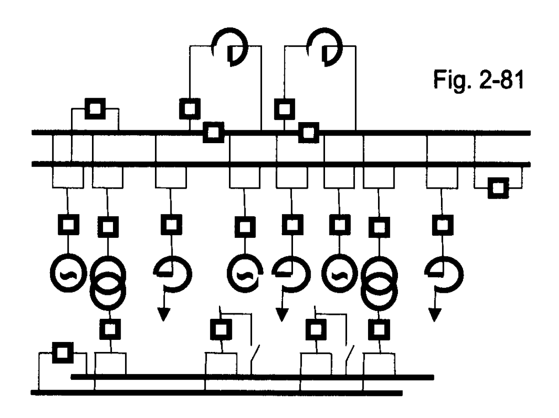


Fig. 2-81

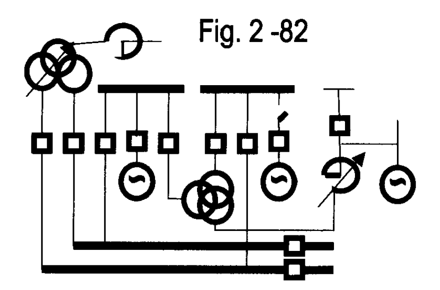
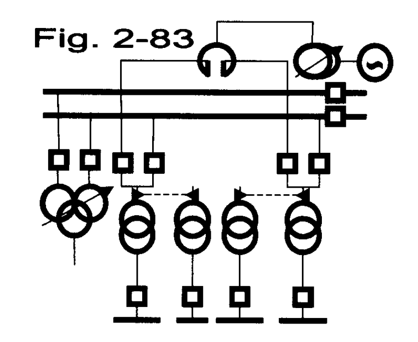
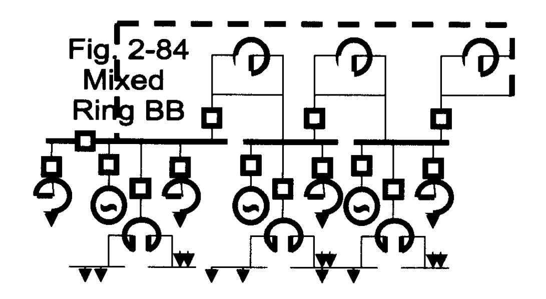


Fig. 2 -82


Fig. 2-83


Fig. 2-84
Mixed
Ring BB

# Chapter III

# Single Line Diagram

**The network is working according to the 3 phase performance where the circuit will be compressed when drawing. The single line diagram (SLD) is the solution for such a problem overcoming. Therefore, the (SLD) will be the base for a design process for a station in spite of its un-completely for all items in the circuit. It is still the best solution for the complex diagrams on sheets. Otherwise, the 3 wire diagram may be implemented but only where required. Then, the process of design a station begins at the (SLD) and consequentially the next discussion will be important for the subject under interesting.**

## 3.1 Basic Rules

**There some rules must be determined before beginning such as:**

### 1- The level of power

**This means that the bulk power or small or medium. Also, whether the power utilized in site or far away or both.**

### 2- The level of voltage

**The voltage level is very important to decide the type of installation so that the simple or complex connections may be considered. This level plays a great role in the design process from the all items of design view. This will be explained later in more details.**

### 3- The number of units

**The number of units differs from the level of the power in that the units may be small for a small station or a small for a big station.**

### 4- The area available

**This area may be opened value if the station is built in the desert or a certain area not more inside a zone. The design may be moved towards a certain technology with different styles of items. Then, various possible can be proposed.**

### 5- The type of station

**Type of station can be classified as known as P. S. or S. S. or distribution or others as given in the last above chapter. It may be installed in an open area or inside and other type classifications as will be explained later.**

**6- There many different types of CB which are used in HV level so that the type of CB plays a great role in the shape of the station. The CB type is an important item although it has nothing in the single line diagram. That is the type of CB affect the design of the station while the (SLD) is not depending on it. The types of CB may be $SF_6$, Oil, Air Blast, Vacuum or others.**

### The style of CB

### 7- The directions of incoming and outgoing lines

**In order to allocate the direction of the station, the directions of outage connections would be defined. This means that the direction of the sides of the station under design depends on the directions of lines connected. The possible directions can be single, double, triple or multi as well as single level of voltage or more.**

### 8- The possible allowable tolerance in the above items.

**Sometimes, the design will be controlled according to some restrictions. These restrictions will affect the design so that they should be known at first before the design process. Such controllers could influent the shape of the station or the connection or the level of voltage or even the type.**

### 9- Type of auxiliaries required

Auxiliaries include a lot of components that takes a role in the (SLD) when design so that their presence in the station would be considered from the begging. The fire fighting or pumping of water or earthing type may be subjects for the item proposed. This subject will be introduced with explanation next.

### 10- Performance of measuring transformers

The presence of the measuring instruments in a station is essential and their type is important. This related to the protective schemes and circuit used. The relaying style will be a point to lead the design in a certain direction.

These basic rules besides others would be helpful for the design.

## 3.2 Stations

Electric stations can be classified as written below and the different connection for each may be presented.

### 1- Power Stations

It is the station in a network because it is the supply which bring power to the consumers. Their connections depend on the BB style according to some different factors and they may be illustrated next.

a) Single BB single low voltage level output (Fig. 3-1). In this case a standby CB may be installed in the circuit as given in circuit (b).

b) Double generation level BB (Fig. 3-2).

It may be in different shapes of connections as shown in either a (where low flexibility but it can be installed for hydro P. S. or b scheme.

c) Multi level connection (Fig. 3-3): It may be also as HV levels / LV sectionalized BB which means that each section for each main side (Fig. 3-4), a or double voltage double BB with single or double CB style as in circuit b.

On the other hand for typical types of P. S. we introduce some of P. S. as follows:

### I- The thermal P. S.

It is the most used type and the connections for typical stations would be presented in the form:

a) Basic Scheme (Fig. 3-5).

b) Line Reactor Scheme (Fig. 3-6).

c) Large number of units / minimum sections as given in Fig. 3-7.

d) Large 0.4 kV 3 units P. S. as shown in Fig. 3-8.

e) 6 kV 4 units station as in Fig. 3-9.

### II- Hydro P. S.

Similarly, there are some typical connections that may be tailored shortly as:

a) Basic Scheme (Fig. 3-10).

b) General Loading (Fig. 3-11) but is a weak connection for flexibility, reliability and parallel operation of transformers.

c) 0.4 / 11 kV Circuit Small P. S. (Fig. 3-12).

They can be classified due to the amount of power as given below:

a) Small P. S. (Fig. 3-13).

b) Normal P. S. (Fig. 3-14).

c) Large P. S. (Fig. 3-15).

### III- Double winging generators

This may be used for any type of station and they mainly divided according to the connection to BB as single BB (Fig. 3-16, a )or double BB system (Fig. 3-16, b ).

## 2- Substations

The transformer stations are known as substations (S. S.) and they may classified as given before according to the purpose setup or down or others. Now, the connection type will be divided into two main poles:

### I- Traditional Pole

This includes some types of connections as:

a) Single supply single BB (Fig. 3-17).
b) Single BB double supply system (Fig. 3-18).
c) General use BC double BB (Fig. 3-19).
d) Double CB double BB (Fig. 3-20).

### II- Improved Pole

The new improved connections cab be presented by:

a) Double feed line single BB (Fig. 3-21).
b) Single feed line double BB (Fig. 3-22).
c) Multi feed line with starting auto-transformer (Fig. 3-23).

### III- Advanced Pole (Sectionalized HV BB)

It is the most suitable one for bulk power S. S. and the connection diagram has been drawn in Fig. 3-24 .

## 3- Distribution Station

The distribution stations vary in shape according to the number of transformers inside such as Single, Double, Triple or Multi Transformer Distribution Station. Each of these will be defined according to the voltage level as:

1- Single outage voltage level
2- Multi outage voltage level (Fig. 3- 25)
3- AC / DC Converting Station
4- Rail Way Station (Fig. 3-26)

Also, all of these stations could be arranged with respect to the SLD in the form:

1- Radial Outage Scheme (Fig. 3-27)
2- Ring Feeder System (Fig. 3-28)
3- Multi Feeder Distribution (Fig. 3-29)
4- Double BB Schemes (Fig. 3-30)

Finally the switch Stations may be classified as a CB arrangement station for the purpose of flexibility of different connections between either stations lines in a network.

# 3-3 Auxiliaries

Auxiliaries in an electric station depend on the type of Loads needed inside.

For a power station we need : (water / Fuel pumping – Cooling fans & pumps – Air Compressors – Fire Fitting – Lights – Rectifiers – Control – Measurement & Recording – Heaters - Others)

Supply facility type appears also, as a basic factor in the determination of such auxiliaries such as : (Main BB – House Transformer – House Generator – Shaft Generator – Motor Generator Set – Outage of the distribution network)

On the other hand the types of loads may be indicated in classes as High importance (class A) or Normal load (class B). Similarly, characteristics of the supply take a role in the process where it is A C or D C where usually both are presented and required. Therefore, the scheme configurations can be played a role as given in items below.

## I. Connection for Small Power Stations

This item may be considered for many connections but here the fundamental scheme will be introduced as:

1- Main bus supply (Fig. 3-31)

2- House turbo- generator supply (Fig. 3-32)

## II. Large Stations

When the power is increased the connection diagram become more complicated for importance of supply. The P. S. in these cases needs the big heavy power transformers so that it may be the outage face for it. Then the classification of schemes for heavy power electric station would be:

1- Double supply Type (Fig. 3-33)

2- Load class principle (Fig. 3-34)

3- House transformer at generator leads (Fig. 3-35)

4- Shaft generator supply (Fig. 3-36)

## III- Typical Circuits

There are many known typical circuits for the connections of auxiliaries such as

1- Motor generator unit (Fig. 3-37)

2- Main pumping for water station (Fig. 3-38)

3- Pump station with protection (Fig. 3-39)

4- Schemes for limiting current devices (Fig. 3-40)

# 3- 4 : Three Wire Diagram (3WD)

any single line diagram can be translated into a 3 wire diagram where the neutral and earthing connection will be appeared. It is the complete view of electric circuit which must be the base in the final revision after design. However, the SLD is always the first step and the 3 wire must be deduced from it. The SLD is still the main item in the design that would be followed by some other steps. This will be more clear at the end of the given book after the studying all presented important subjects. On the other hand the protection schemes could not be illustrated completely on the SLD while the 3WD gives all details on the drawing.

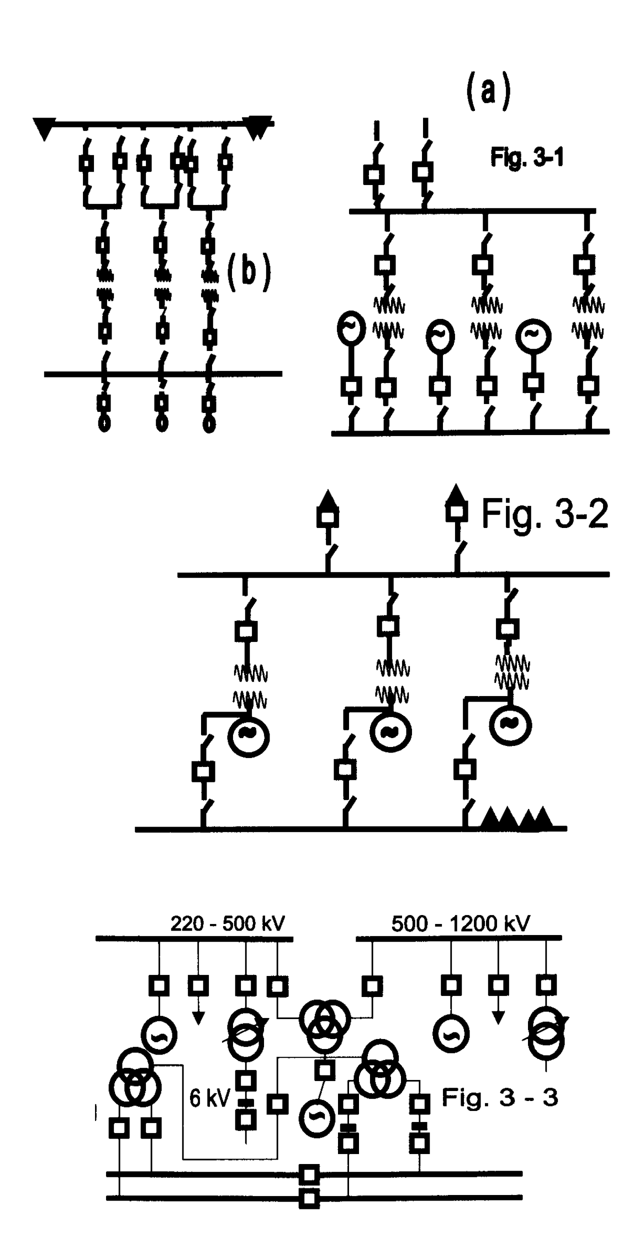



Fig. 3-1

Fig. 3-2

Fig. 3 - 3

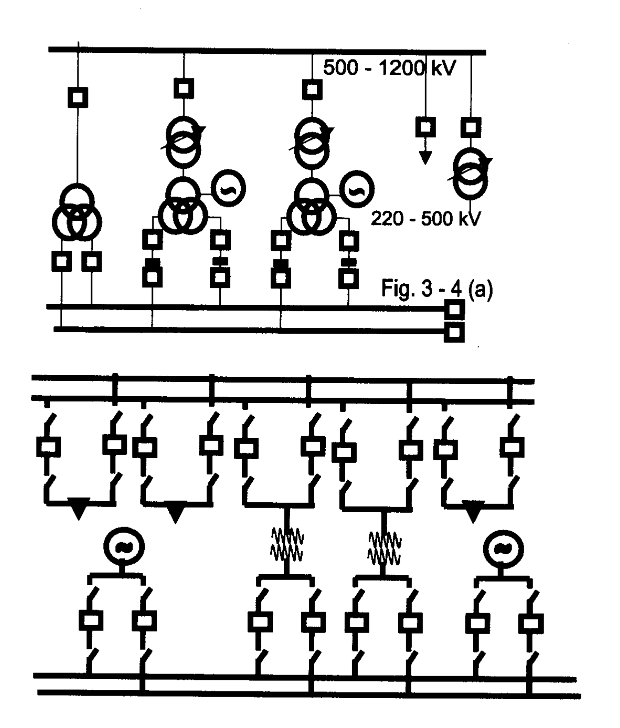
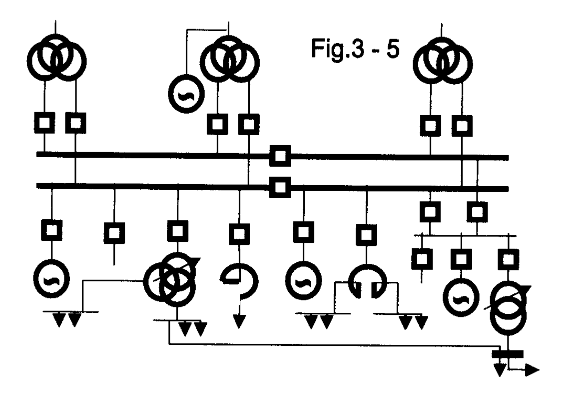


Fig. 3 - 4 (a)

**Fig. 3-4 ( b )**


Fig.3 - 5

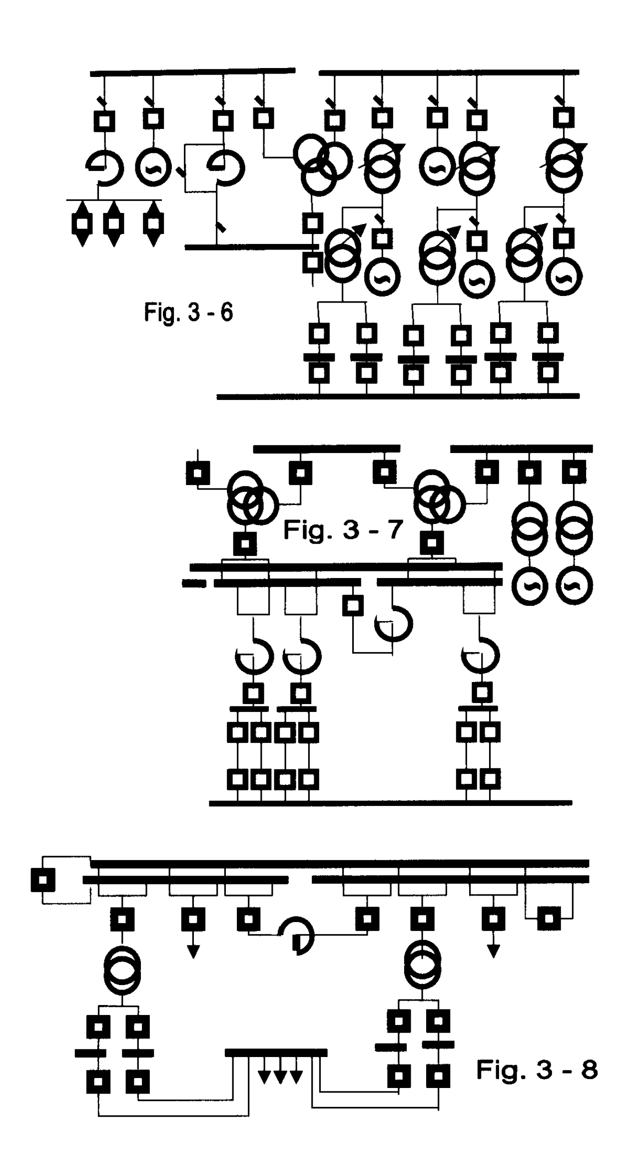
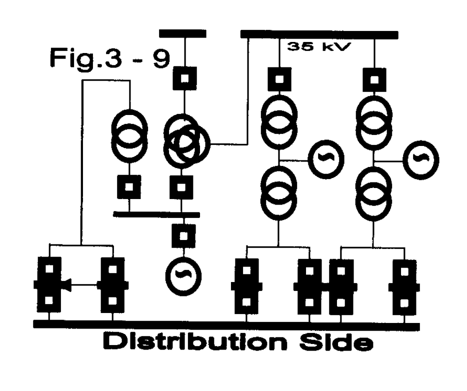
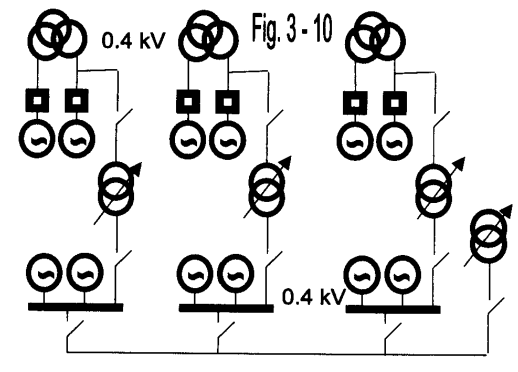


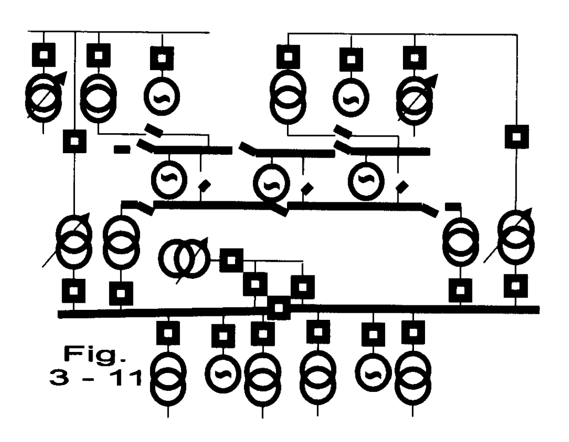
Fig. 3 - 6

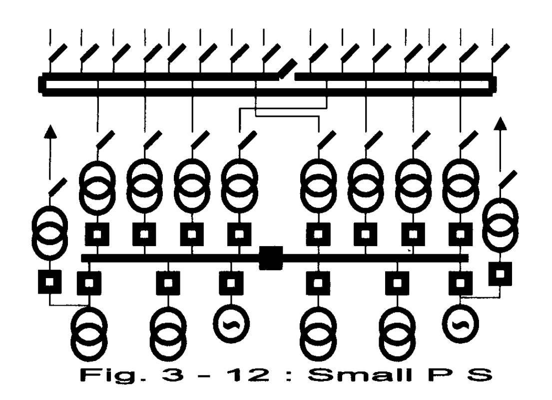
Fig. 3 - 7

Fig. 3 - 8


Fig.3 - 9
35 kV
Distribution Side


0.4 kV
Fig. 3 - 10
0.4 kV


Fig. 3 - 11


Fig. 3 - 12 : Small P S

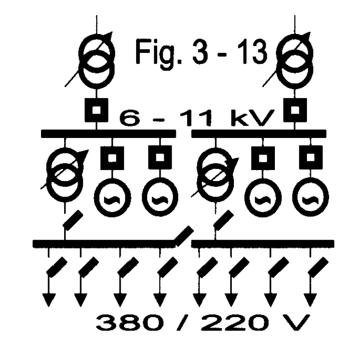


Fig. 3 - 13

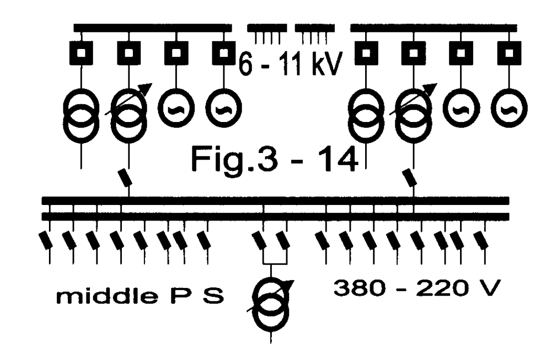


Fig.3 - 14

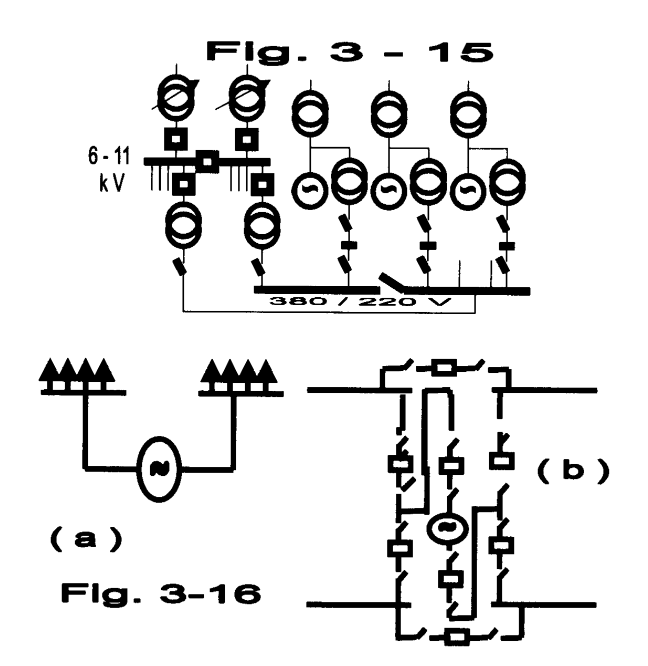


Fig. 3 - 15

Fig. 3-16

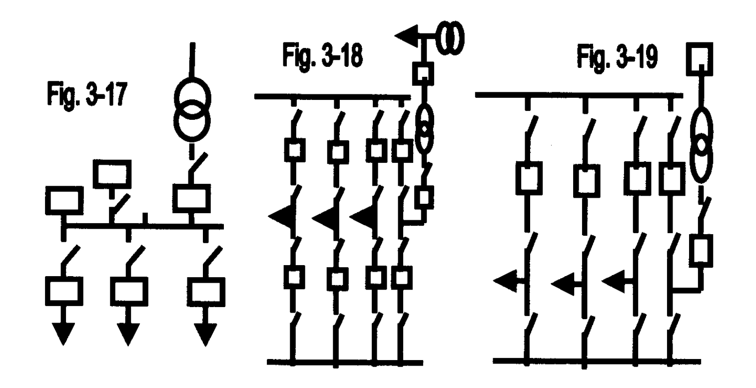
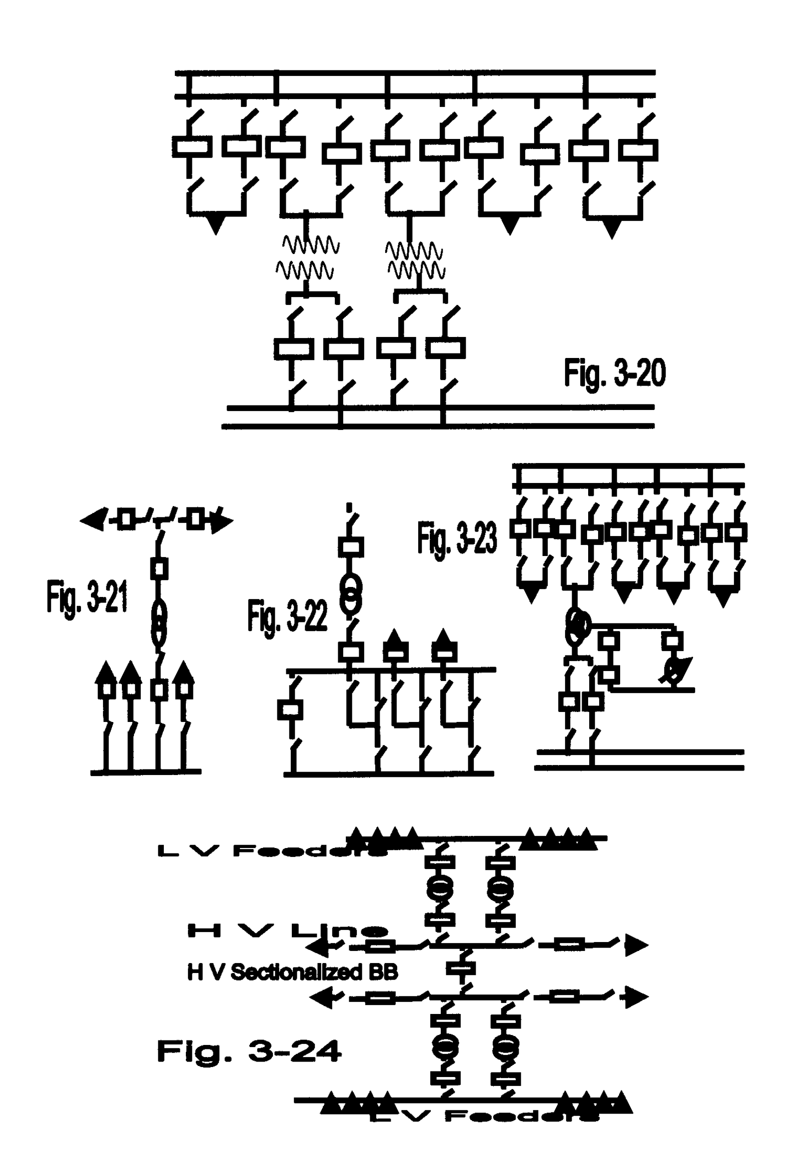
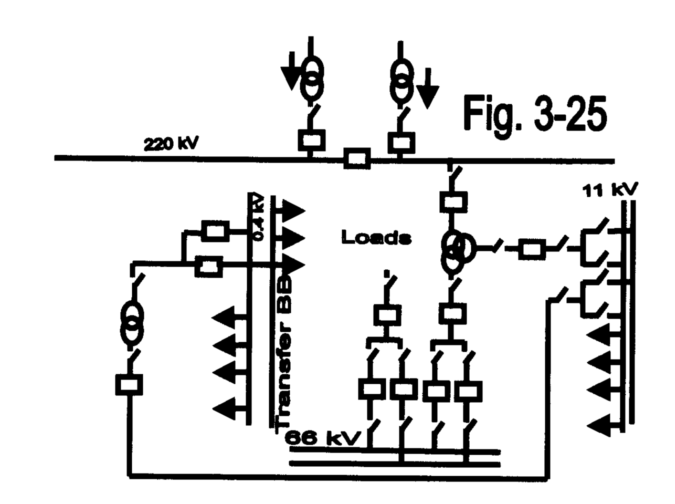
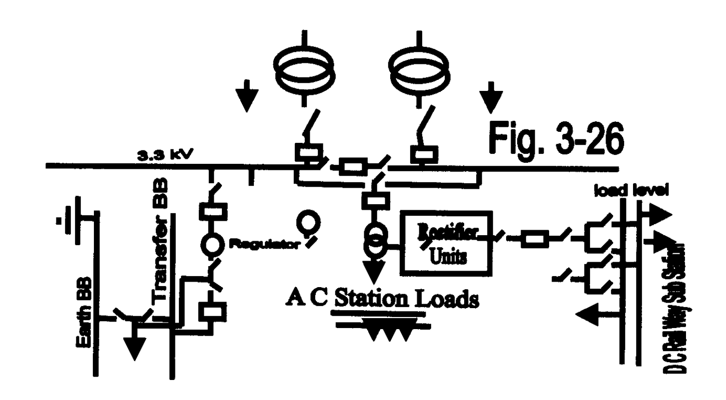

Fig. 3-17

Fig. 3-18

Fig. 3-19


Fig. 3-20
Fig. 3-21
Fig. 3-22
Fig. 3-23
L V Feeders
H V Line
H V Sectionalized BB
Fig. 3-24
L V Feeders


Fig. 3-25
220 kV
11 kV
0.4 kV
Loads
Transfer BB
66 kV


Fig. 3-26
3.3 kV
load level
Earth BB
Transfer BB
Regulator
Rectifier
Units
A C Station Loads
D C Rail Way Sub Station

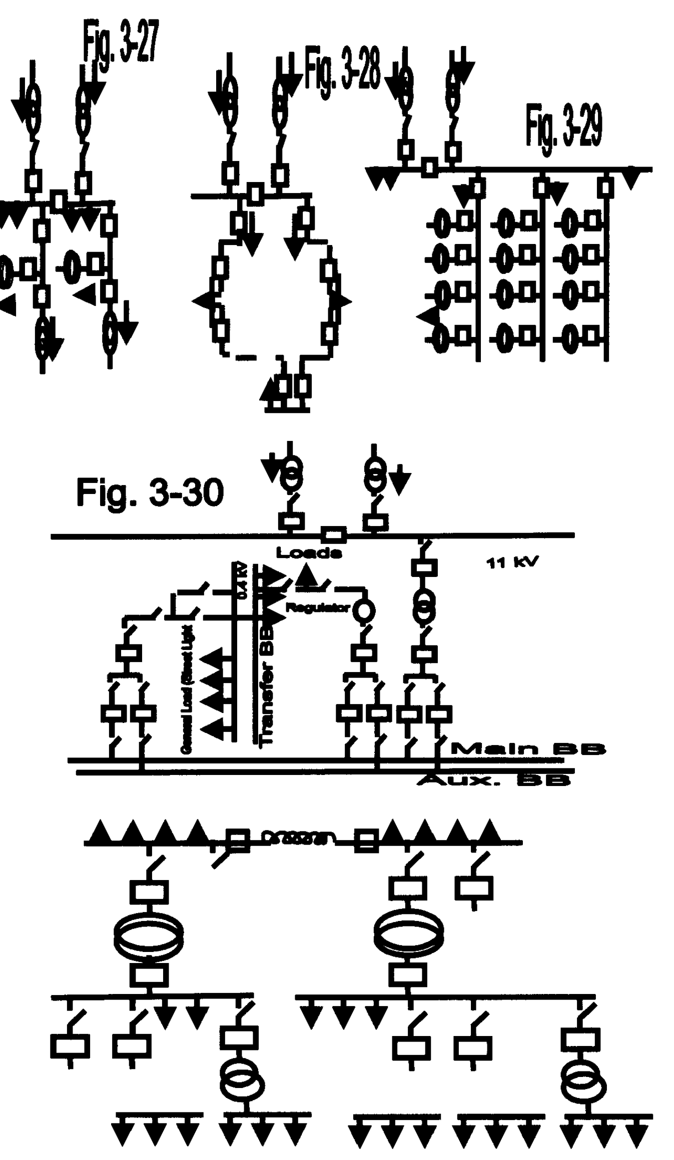
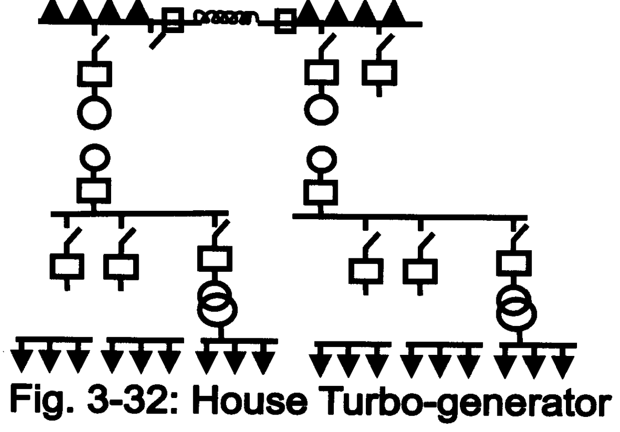



Fig. 3-31: Main Bus Supply


Fig. 3-32: House Turbo-generator

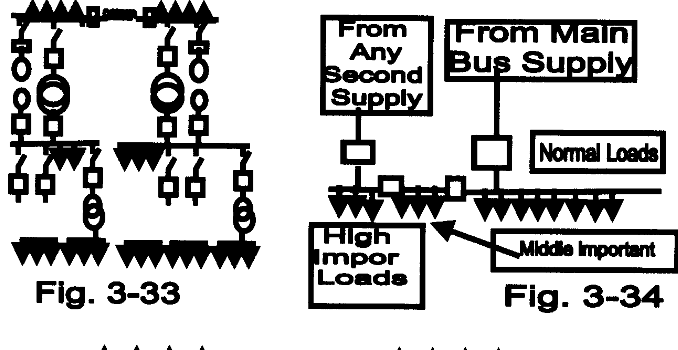
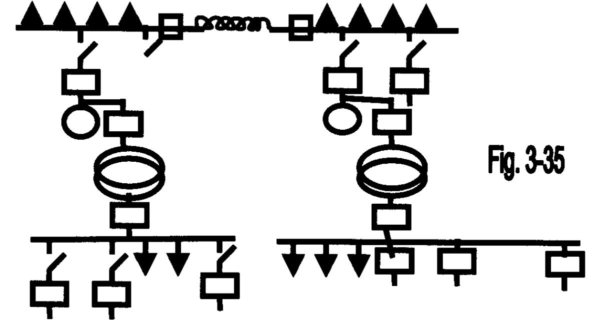


Fig. 3-33

Fig. 3-34


Fig. 3-35

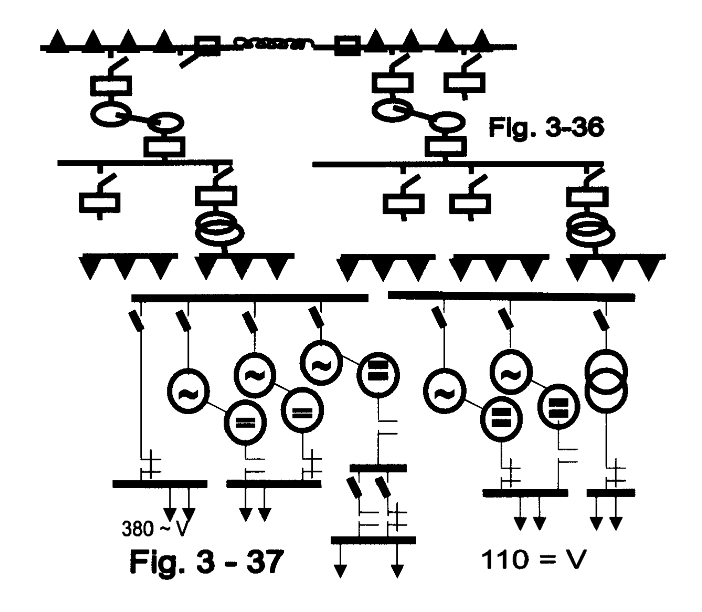



Fig. 3-36

Fig. 3 - 37

Fig.3 - 38

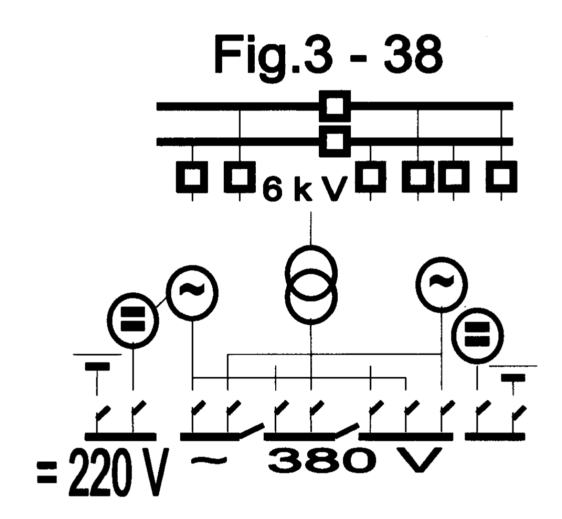


Fig. 3 - 39

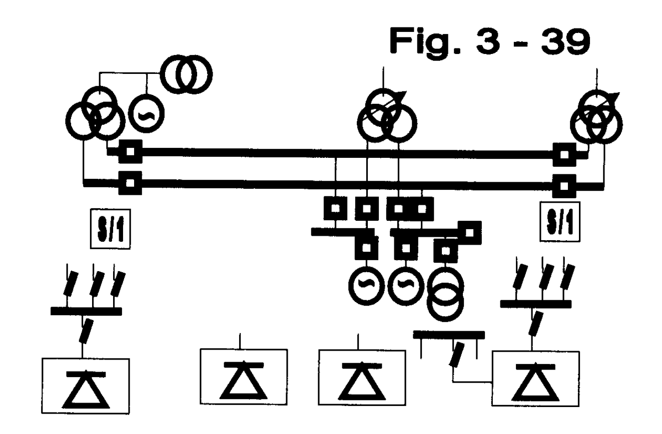
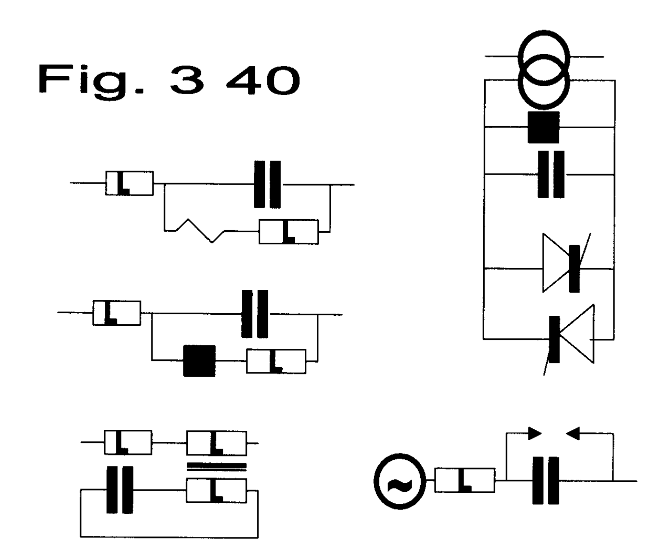



Fig. 3 40



# Chapter IV

## Basics for the Layout

**The title of LAYOUT is an important for the designers of any construction but it is very urgent for electric stations from the point of electricity view. This means that the layout of a station must reflect well all components inside and consequentially, the electric devices and tools used. It may be clear if the basics of the layout are studied and explained. Also, this needs some necessary items to be discussed according to the next presentation.**

### 4-1 Rules

**From the first rule we find the minimum permissible distances for the components in a station in general where Fig. 4-1 presents the dimensions of an isolating link 500 kV and Fig. 4-2 (a, b) shows the permissible distance between the edge points such as phase to phases either spacing F or e or K or to adjacent circuit D – phase to earth A or S or g or n – phases to grounded body S or n . Also, the height of life phases u and cell width d are indicated.**

**The given practical values are listed in Table 4-1 where both drawings are considered. These dimensions are a base for the design process.**

**Table 4-1: Minimum Distances, m**

| Paramet er, (m) | 110 (kV) | 150 (kV) | 220(kV) | 330 (kV) | 500 (kV) |
|---|---|---|---|---|---|
| a | 8 | 11.5 | 11.75 | 18 | 29 |
| b | 9 | 9.5 | 12 | 19.6 | 26.8 |
| B | 12.5 | 15 | 18.25 | 20.4 | 29 |
| x | 10.5 | 16 | 20.5 | 31.5 | 45 |
| d | 9 | 11.1 | 15.4 | 22 | 31 |
| e | 2.5 | 3 | 4 | 8 | 11 |
| g | 2 | 2.55 | 3.7 | 4 | 5.5 |
| z | 7.5 | 8 | 11 | 11 | 14.5 |
| u | 11 | 13 | 16.5 | 16.5 | 23.6 |
| k | 3 | 4.25 | 4 | 4.5 | 6 |
| n | 1.5 | 2.13 | 3.25 | 3.5 | 5 |

**Similarly for the shown components in Fig. 4-3 the corresponding dimensions are listed in Table 4-2.**

**Table 4-2: Minimum Distances for Fig. 4-3, m**

| parameter | 10/35(kV) | 110 (kV) | 220 (kV) | 500 (kV) |
|---|---|---|---|---|
| A | 0.2/0.4 | .9 | 1.8 | 3.75 |
| F | 0.22/.44 | 1 | 2 | 4.2 |
| S | .95/1.15 | 1.65 | 2.55 | 4.5 |
| Q | .95/1.15 | 1.65 | 3 | 5 |
| G | 2.9/3.1 | 3.6 | 4.5 | 6.45 |
| D | 2.2/2.4 | 2.9 | 3.8 | 5.75 |

These dimensions for the indoor type stations are given in Table 4-3.

Table 4-3: Minimum Distances for indoor cases, cm

| Param-eter | 3 (kV) | 6 (kV) | 10 (kV) | 20 (kV) | 35 (kV) | 110 (kV) | 150 (kV) | 220 (kV) |
|---|---|---|---|---|---|---|---|---|
| A | .065 | .09 | .12 | .18 | .29 | .7 | 1.1 | 1.7 |
| F | .07 | .1 | .13 | .2 | .32 | .8 | 1.2 | 1.8 |
| S | .095 | .12 | .15 | .21 | .32 | .73 | 1.13 | 1.73 |
| Q | .165 | .19 | .22 | .28 | .39 | .8 | 1.2 | 1.8 |
| G | 2 | 2 | 2 | 2.2 | 2.2 | 2.9 | 3.3 | 3.8 |
| D | 2.5 | 2.5 | 2.5 | 2.7 | 2.7 | 3.4 | 3.7 | 4.2 |
| S | 4.5 | 4.5 | 4.5 | 4.75 | 4.75 | 5.5 | 6 | 6.5 |

The types of isolating links are given as projections for the layout condition, i. e. elevation and plan drawings.
It is notices that there various types of I. L. and to operate as the first moves horizontally. The second moves horizontally with an axis at the middle of I. L. while the third vertically. This means that there are many types that can be chosen for a design application.

## 4-2 Measuring Instrument

The Layout Of Individual Equipment for measurement or switching or even protection is a fundamental item in the design. So, the individual layout of the most important equipment is shown in Fig. 4-5.
Current transformers have two terminals (Input & Output) while the voltage transformer has only one terminal because the second is earthed through the windings. Also, the arrester is usually, similar to the P. T. while the CB differs from the I. L. in that the arcing chamber is projected as a box. This CB differs from transformers in that the insulation height is the same for CB but there is a difference in the transformer.
It is important to point that each element or component in the station is given for a single pole type except the transformers up to 500 kV and generators. The single pole style for CT and PT may induce a difficulty degree in the application of protection schemes that must be taken into account during the design practice.

## 4-3 Cells

A station must be divided into some equal zones where each zone should be responsible for all connections for a certain item such as entrance of a transmission line or feeder or even others. This means that the station will take a rectangular shape in which many small rectangles (cells). This seems to be a simple illustration for the layout. So, each cell means an individual connection that should be ended at the BB inside. The given style of cells is acceptable for both types of stations indoor or outdoor as well as the panel system.
It is practically used for the typical type of stations specially for the small power distribution stations. It can be tailored for different levels for example as written next.

## I- Terminal Steel Structure Stations

This can be illustrated as the steel structure units as given in Fig. 4-6 for a typical 6 / 10 kV distribution station or single portal 35 kV station as shown in Fig. 4-7and also, for the HV stations. The HV stations may be taken for example thetypical 110 kV S. S. of Fig. 4-8 (a) and the steel typical 140 kV S. S. as presented in Fig. 4-8(b).

## II- Outdoor End Stations

It is clear that the abroad of cities may leave the outdoor available but under the restrictions of human security for operation and others. This means that the regulations for the installation of such stations must be considered for safety rules according to the specifications. On the other hand, there are simple units can be considered as :

1- Basic diagrams (Fig. 4-9).
a) 6.5 MVA Unit (Fig. 4-10).
b) 1.6 MVA Station (Fig. 4-11).
c) (Out / In) door station (Fig. 4-12).
2- Double unit (2 x 6.3 MVA) feeding station (Fig. 4-13).
3- 35 / 6 kV feeding (Out / In door) type
a) Basic circuits (Fig. 4-14).
b) Single unit (Fig. 4-15).
c) Double unit (Fig. 4-16).
4- Outdoor 0.4 kV supply
a) 11/0.4 kV station(Fig. 4-17).
b) 35 kV transformer cell (Fig. 4-18).
c) 11 / 06 kV supply (Fig. 4-19).
d) Panel 1 MVA (Fig. 4-20).

This is also, typical for the distribution part in a station as indicated for a 110 kV, 6.5 MVA distribution station (Fig. 4-21) or for the block style as given in Fig. 4-22.. All the given circuits and their layout are presented for the sample purpose in order that the next discussion for the design process may be more simple.

## III- High Voltage Stations

This for example can be illustrated through some typical stations according to the voltage level as follows.

a) 110 kV S. S. (Fig. 4-23)
b) 220 kV Switching Station (Fig. 4-24)
c) 330 kV level (Fig.4-26)
This may be in more detailed schemes as:
i) SLD (Fig.4-25)
ii) Line Cell
iii) Transformer Cell
iv) Principle Dimensions
d) 500 kV Yard layout
Similarly a basic style can be considered for
a- Line Cell. b- Line - transformer Connection
c- Double CB d- Triple CB

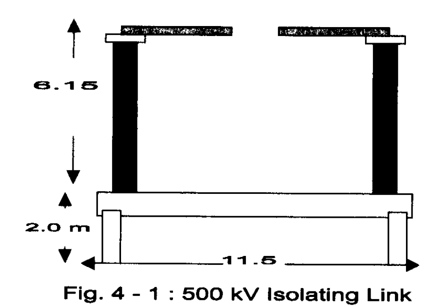



Fig. 4 - 1 : 500 kV Isolating Link

Tower Top
g
e
u
330, 500 kV
Tower Top
n
K
u
110, 150 kV
Tower Top
n
K
u
ground
220, 330 kV
Tower Top
g
e
u
ground
110, 150, 220 kV

Fig. 4-2 ( a )

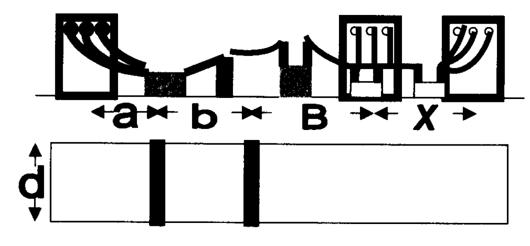



Fig.4 - 2 ( b )

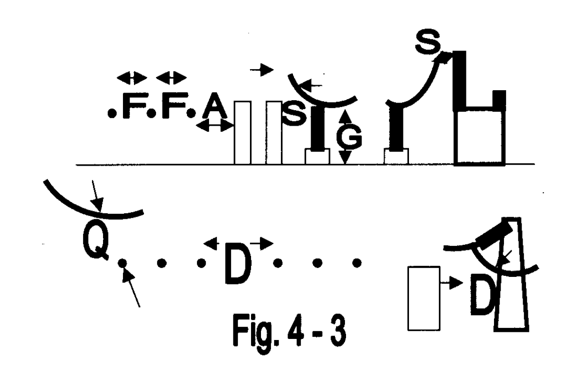



Fig. 4 - 3

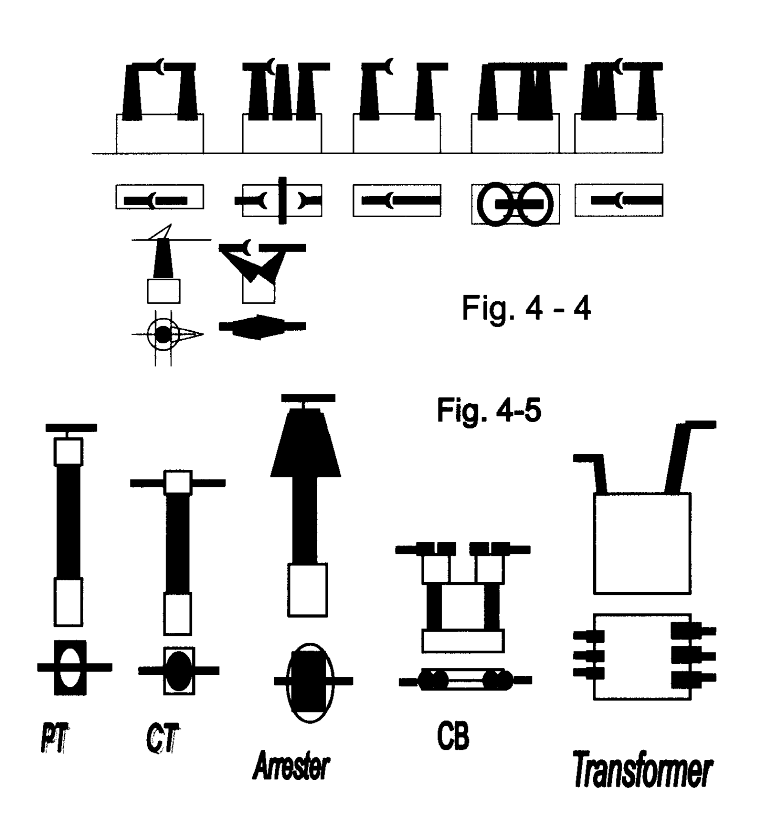



Fig. 4 - 4

Fig. 4-5

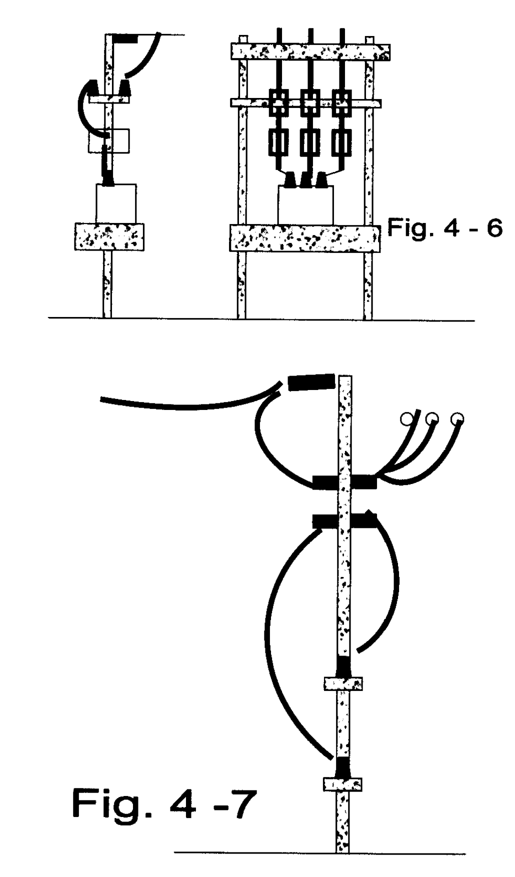
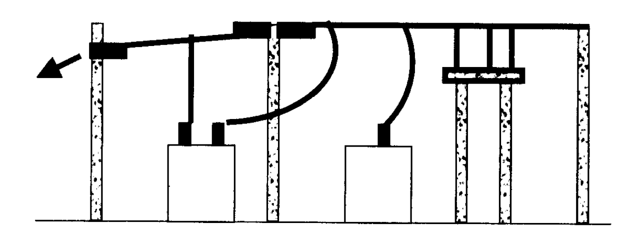


Fig. 4 - 6

Fig. 4 -7

Fig.4 - 8 ( a )



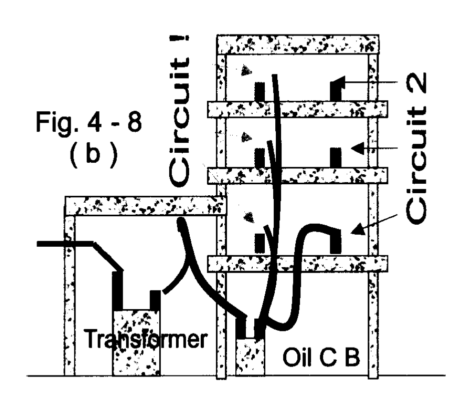
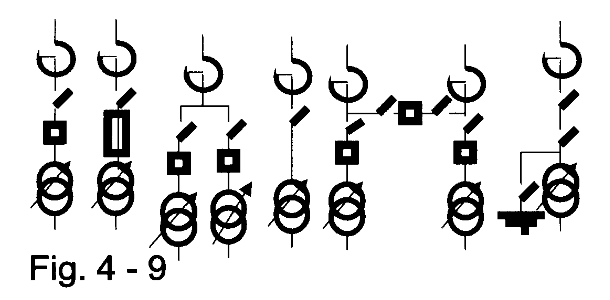


Fig. 4 - 8
( b )


Fig. 4 - 9

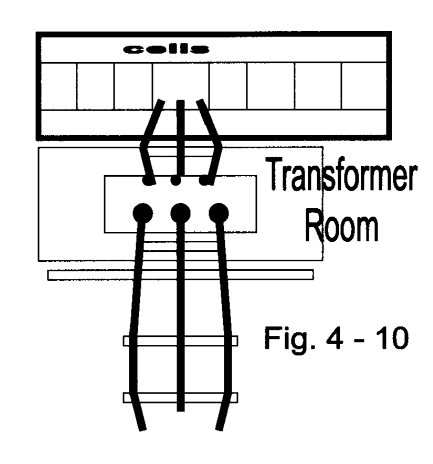


Fig. 4 - 10

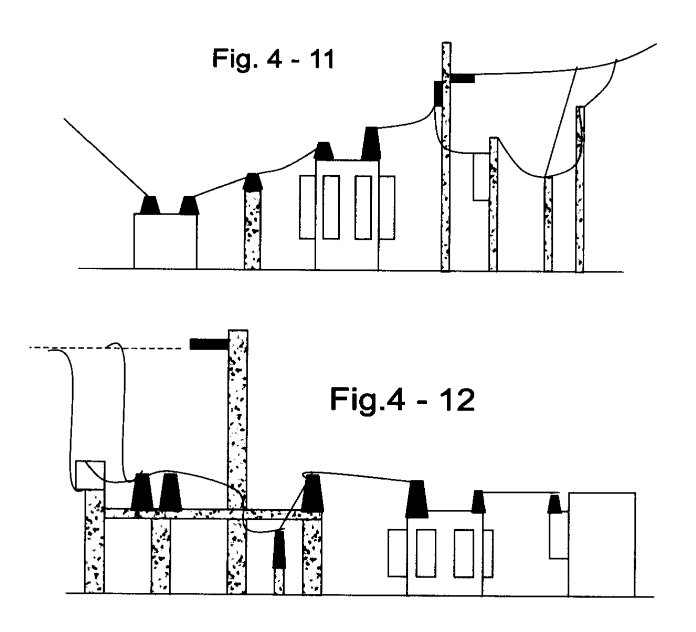
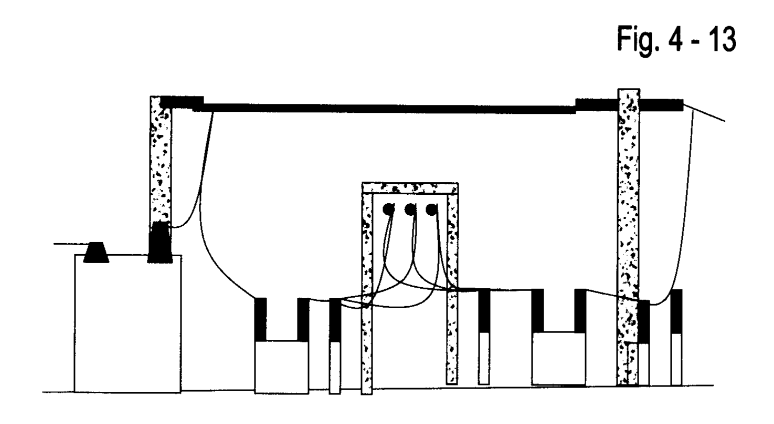


Fig. 4 - 11

Fig.4 - 12

Fig. 4 - 13



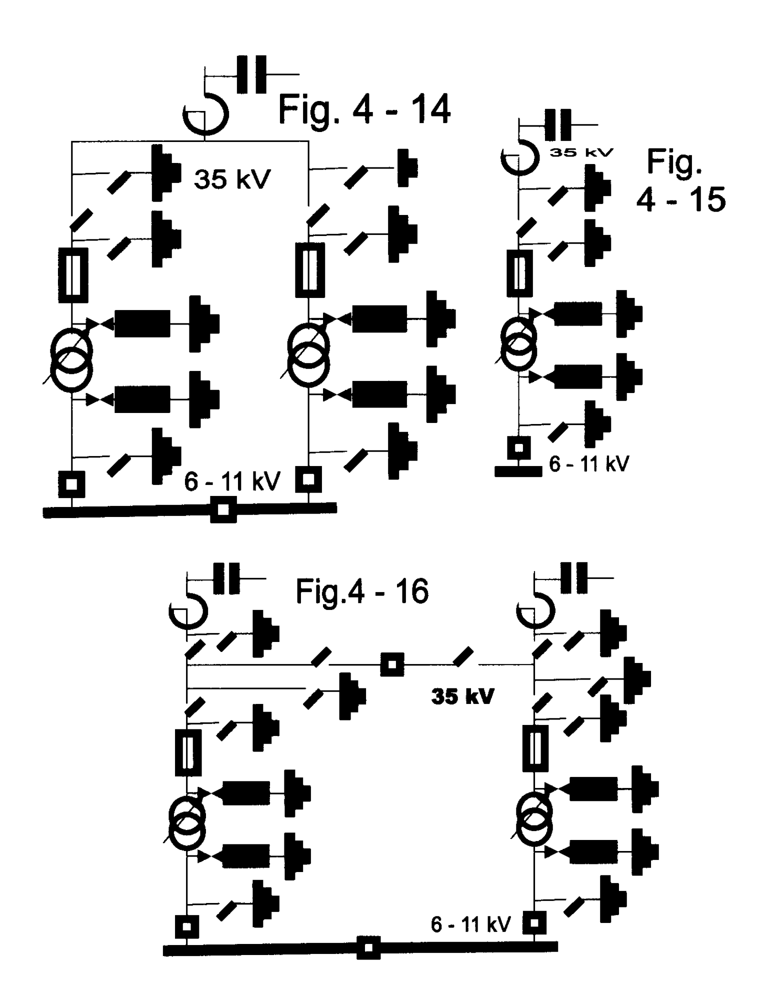

Fig. 4 - 14
35 kV
6 - 11 kV
35 kV
Fig.
4 - 15
6 - 11 kV
Fig.4 - 16
35 kV
6 - 11 kV

Fig. 4 - 17 : 11 / 0.4 k V Station

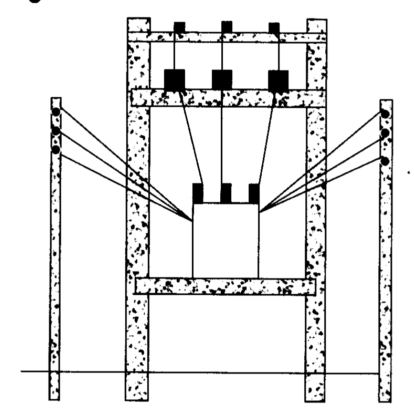


Fig. 4 - 18



Elements in a transformer cell

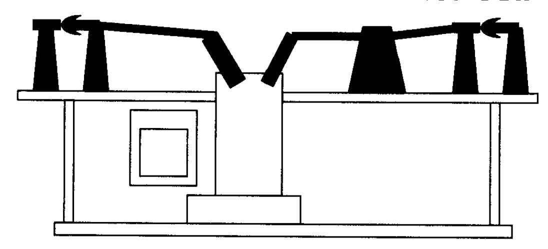
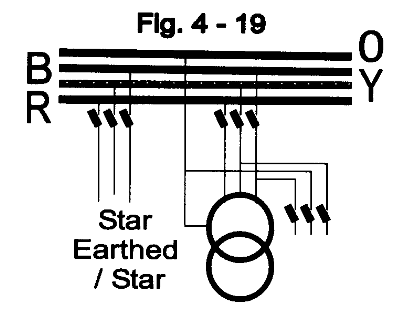
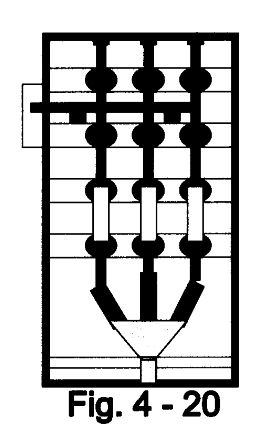
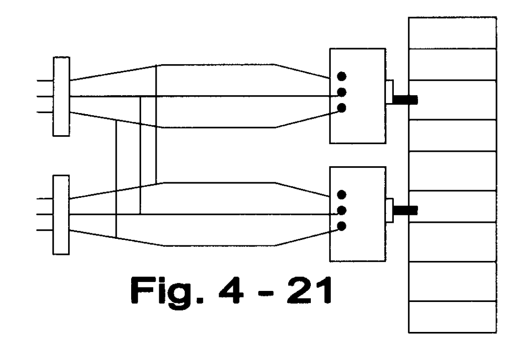


Fig. 4 - 19




Fig. 4 - 20


Fig. 4 - 21

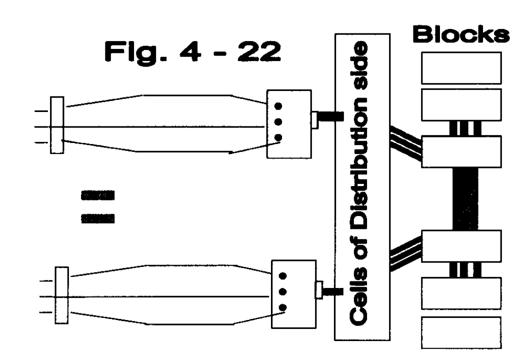


Fig. 4 - 22

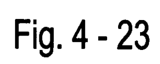


Fig. 4 - 23

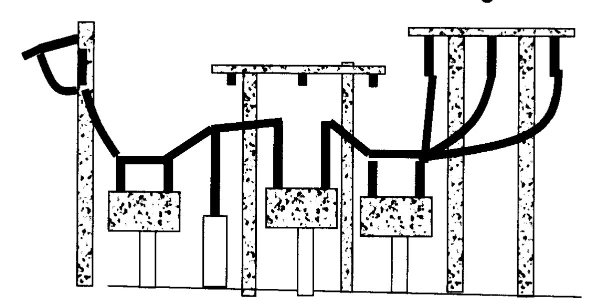
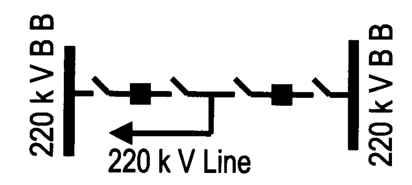


Fig. 4 - 24



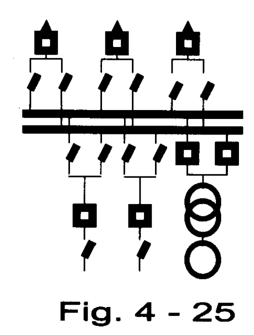



Fig. 4 - 25

# Chapter V
# MATHEMATICAL PROCEDURE

**It is known that the process of design for a station depends on the factors affecting the situation, environment, the condition of operation, the geographic location as well as financing. So, the procedure of calculations of different items inside a station must be explained in order to make the process very easy. The contents of a station with its various shapes and types have been illustrated and consequently the computation of all components in the station may be the aim to reach.**
**Otherwise, the mechanism of evaluation appears to be a complex one so that it can be implemented through the superposition technology. Therefore, the element will be the item of the work but with its parameters included for the design. Such concept would be tailored into the following categories. This includes the elements inside each cell in the layout, the electrical parts inside, the mechanical sections, the chemical components and the civil operations included in the station parts.**

## 5-1 Bus Bar Geometry

**The calculation principle depends on heat accumulation due power loss as well as on the current density carrying conductors. This may be analyzed for the maximum allowable value of current passing through any section of the BB. So the current effect would be inserted in the process besides some different factors as given next.**

### 1- Current Density Dependency

**Thus, the diameter of the BB conductor will be calculated as:**

**BB cross sectional area = maximum current / current density (5-1)**

**This formula must be modified according to the design factor and then, the value could be moved to the next higher value of the standard conductors.**
**Accordingly, a table style, for the evaluated BB conductors at all levels of voltage, can be used in the form:**

**Table 5-1: The BB diameters**

| Voltage | Calculated | Designed | Standard diameter | Required length |
|---|---|---|---|---|
| HV | | | | |
| MV | | | | |
| LV | | | | |

**During that, the check for Diameter Calculation may face a problem. The last column may be impracticable so that a Bundling base will be considered.**

### 2- Voltage Stress

**The voltage level will take a main role in the determination of the Spacing between conductors of BB and their Height in order to get the final geometry of BB. The conductor allocation will be horizontal for out door installations will it may be placed in different shapes as given before. This case may be expanded for the indoor stations due to the different types of geometry possible for the BB. All cases must be taken into account when the designer prepares his project for a station.**

## 3- Corona Check

**It is known that corona is a form of the self-sustained discharge (with a radius $r_q$), typical for the sharply non-uniform fields. It is important to indicate that volume charge of the separate phases mutually interacts with each other. As the polarity is changed per a cycle for the AC circuits, the charges on a conductor will be attracted in the second half-period. For maximum spacing of the volume charges, the intensity of the field on the surface of a conductor (radius= $r_o$ ) will be considered as a constant ($E_r$) value during the half period. Its value may be equated to the critical value( $E_c$ ) as:**

$$Er = constant \quad , \quad E = Ec \; . rq \; / r \qquad (5\text{-}2)$$

**Also, the maximum voltage for the greatest volume discharge from the axis of conductor with corona can be theoretically found by the approximate formula:**

$$Vmax2 = K\,T\,Ec\;ro \qquad (5\text{-}3)$$

**For example using this equation, if ro = 1.25 cm , K=1.8 (cm/s) / (V/cm), Ec = 36 kV/cm and 50 Hz, the greatest separation for corona will be calculated as 40 cm. This value is less than the actual spacing between conductors.**

**Corona causes a loss, which is determined as the charges transfer from the coronised conductor to the other. It is a leakage current for the DC circuits while it differs for the AC networks. The corona power loss (P) may be experimentally deduced by the equation:**

$$P=[241(f+25)/\delta](r_o/S)^{1/2}(V_{ph}-V_o)^2\times 10^{-5} \quad kW/km\;/phase \qquad (5\text{-}4)$$

**Where**

**$\delta$ Relative air density**
**$r_o$ Conductor radius (cm)**
**S Mean geometrical distance between conductors (cm)**
**f Frequency (Hz)**
**$V_{ph}$ RMS value of the phase voltage (kV)**
**$V_o$ Calculated voltage close to the critical corona voltage.**
**It follows the formula:**

$$V_o = 21.2\;\delta \log(S / r_o)\;m_1\;m_2 \qquad (5\text{-}5)$$

**Also, the coefficients $m_1$ and $m_2$ are the smoothness and weather coefficients, respectively. In order to reduce the corona loss at AC networks, maximizing the radius of the conductors is a target. The absence of corona loss in fair weather can be evaluated by getting the phase voltage to be less than critical close voltage $V_o$**
**This item will change the above results to reduce the loss in the BB, especially, with the continuous loading during 24 H a day.**

## 4- Final Standard Dimension

**After the actual standard conductors suitable for the design, the choice of the final standard dimension of BB has been found. This finishes the electric part of BB design, and consequentially, transfers our job to the mechanical design.**

## 5-2 Cell Dimension

**The mechanical design is mainly depends on the maximum strength affecting the holding points at the ends of the BB conductors (Fig. 5-0).**
**Figure shows some distributed forces where the connections of cells to the BB must be held to fix the cell contents to BB. The calculation may be done for equal forces at these points. Such determination can develop the needed type of string at both ends. Due to the high strength in large HV stations, the double string insulator type will be better than the single. The practice indicates the style of double string is the most required one.**

For indoor stations the strength will be supported on a point instead the tension type of Fig. 5-0. In this case the BB may be a pipe or bar so that it must be fixed at only one end. The other end should be relaxed fixing to permit the expansion process with heat rise due to current passing. The portal design can be achieved on the mechanical design of BB while sectionalisation can develop the performance of such design. This means that the maximum strength may be reduced when decreasing the distance between the portals at both ends. Thus, a design will be completed.

Table 5-2: The individual elements for a cell

| element | Calculated | Designed | Standard value | place | Required quantity |
|---|---|---|---|---|---|
| insulator | | | | | |
| clamp | | | | | |
| portal | | | | | |
| support | | | | | |

The above calculations must be translated into tables to find both the type and the quantity required for the installation as given for example in Table 5-2. The summation quantity for all cells may be found from the individual table as Table 5-2 to be expressed as in Table 5-3.

Table 5-3: The Final Requirements

| element | Standard value | Required quantity | price | cost |
|---|---|---|---|---|
| insulator | | | | |
| PT | | | | |
| CB | | | | |
| Alternator | | | | |

Another table could be done to resume the cost of transportation, customs, installation, testing, maintenance, training and others to get the total final cost for the station.

In order to get the above total requirements, the cell dimension must be determined as done for the BB above. Always, the calculations of conductors of a cell depend on that of the BB itself to unify the conductor diameter. Spacing of a cell is the same as for the BB to prevent the corona loss. The contents of a cell may be tabulated and another table to collect all cells in each equal voltage level. Sequentially, a sum table for all BB sections and all BB at all voltage levels can be generated before the final table for the cost calculations. All types of cells may be inserted as:

### a) Single horizontal Level Cell

Here the term horizontal indicates that the installation of all elements of the cell is based on a horizontal plane as shown in Fig. 5-1.This also related with the subject of cost due to the introduced plus elements through out the different components because of the symmetrical allocation of cells or the supporting feature required.

**This horizontal shape of installation is the normal used characteristic over all the world and it is suitable for all countries inside cities or out side. This is applied for either power stations or substations and also, the distribution stations. The given above tables are taken for this type of installation so that it is convenient to treat the design feature by the designers.**

### b) Multilevel Cell

**It is important to see that sometimes we need to supply a place on a hill or on mountain so that the horizontal ground cannot be found. Then, the replacement of it in a new style for the installation of a station will be a major requirement. Thus, the non horizontal shape of installation will be appeared leading to the different types of this installation.**

**Figure 5-2 shows an example for a double level cell installation while the connection between the elements will be subjected to a certain fixation to eliminate the conductors of high voltage from the ground This is ruled by the feature of spacing for the normal HV wires away from the earthed points or metals near the HV wire. This will raise the number of supports to fix the wires as it is shown in Fig. 5-2.**

**The style of double level ground may be developed into a the multi level cell is given in Fig. 5-3. This may be more clear with the shown wire hanging between different elements of the cell.**

**In other words, different styles of a cell according to the installation of the joint point between IL and CB in double BB systems may be taken into account as:**

### a) Underground Style

**Using this style the connections between I. L in a cell will be implemented through underground cables. This minimizes the distance between them and so, the land required for other types of connections. It also, will be reflected on the cost of land as well as the conductors but the cables will be more expensive. This is the idea from the economic point of view unless the reflected wave process would be considered. The cable ends should be used at terminals of the cable as shown in Fig. 5.4 where the cable must connect both common joint of the two isolating link. This joint will be connected to the CB terminal.**

### b) Longitudinal Allocation

**In this case the two isolating links for the double BB connection in a cell could be installed in series inside the cell and consequently, the land needed for a cell will be more. The length of a cell would be increased, getting more land and conductors as well as portals, so that the cost may be increased.**

### c) Parallel Allocation

**This condition of allocation can modify the above case to minimum length of the cell but it will consume a width more than that of the longitudinal one. On the other hand this problem may be solve by the utilization of the spaced area inside the cell, depending on the addition of portals in the site. Thus, the cost will become less than both above cases.**

### d) Vertical Concept

**The vertical direction in the outdoor stations will be more effective because the air above is free. The portal installation will minimize the condition by combining both longitudinal and parallel cases together to give the optimal solution in the subject concerned. The corresponding illustration can be seen in Fig. 5.5 where this concept is suitable for the indoor stations. The two wires connect the CB terminal to the second terminal of the isolating links.**

Then, the Overall Dimensions would be evaluated for both Minimum and Maximum Lengths leading to the Final Dimension for Cells

### e) Area Utilization

As it is explained for the aim of minimizing the cost we need to consider all less dimensions. It may be clear as the combination between Horizontal & Vertical installations for the isolating switches. The represents money going to raise the cost of the station under design because the land price is always going up with its rise rate. This takes as an important factor in developing countries due to the increase in the population in high rates. On the other hand, the stations now are installed inside cities not outside where the land price is great.

Also, the vital aim can be achieved by the replacement of the Direct Connection for the transformer cell inside a S. S. to become with a Reverse Return Style. The goal we can reach will reduce the area to its calculated half value. Figure 5.7 gives the area required for example 10 cells and 2 transformers. This means that the used area for such number of cells may be generally formulated as:

**First total area (fig. 5-7) = 2 × No. of other cells × cell area (5-6)**

In this equation the number of transformers is absent due to the larger number of other cells as in the real situations and applications.

In the figure 5-7, we can see for a 10 cells and 2 transformers cells the area required will be 10 cells from both sides of the BB , i. e. 20 cells area. The required area for the station will be 20 cells area in spit of the number of transformers in it. This is a real condition due to the normal small number of transformers in a station relative to the other cell. Then, we will need a place for 20 cells (10/each side). The direct connection means that the layout of transformers cells to the left of the BB while the other cells must be to the right. This means that the useless area will be calculated as the free land inside a station.

On the other hand, if we use the concept of reverse direction for the connection of transformer cell(Fig.5-8) we can reach a new area less than the old one according to the formula:

**New area with reverse connection (Fig. 5-8) = ( No. of transformers cells + No. of other cells) × cell area (5-7)**

Thus, only 12 cells will be equivalent to the same case in the station and the number of total cells in the station will be only 12 and it represents the required area in the given example.

Consequentially, the saved area will be based as :

**Saved area = Old area – new area (5-8 )**

In order to get the real effect for the new concept the saving ratio in the utilized area can clarify the aim according to :

**Saved area ratio = saved area / old area = 1/2( 1 - No. of Transformers / No. of other cells) (5-9)**

Then, with the technique of reverse type connections for the transformer cells as drawn in Fig. 5-8 we can find that the required area will be only 12 cells. This proves that the saved area is 8 cells. Then, a classification for the area can be taken in three categories:

### 1- Symmetrical Area

This means that all cells must be symmetrical in size, distribution of similar elements and the center line for each item inside the station relative to all cells in.

## 2- Technical Area

**This term means the area required for cells from the point of view of engineering as it has been illustrated in Fig. 5-7 and Fig. 5-8. It is calculated depending on the electric performance for each element.**

## 3- Working Area

**It is defined as the required area for different works such as maintenance or installation and operation or testing.**

**The above analysis for the area of a station could be formulated as:**

**Station area = Technical area + Working area (5-10 )**

# 5-3 Important Features

**All calculations have been international done, and then, results were gathered in the shape of tables. These tables means the standard dimensions for each level of voltage or current according to the concept of application. So, the Table 5-4 presents the standard dimensions for the cells for either outdoor or indoor stations where the dimensions are given in meters. Also, the panel form of cells in constructed according to the same standard and values.**

**Table 5-4: Standard Dimensions For Cells, m**

| Parameter | 6–10(kV) | 35 (kV) | 110 (kV) | 220 (kV) | 330 (kV) | 500 (kV) | 750 (kV) |
|---|---|---|---|---|---|---|---|
| Indoor Spacing | .5-.6 | .6-.8 | 1.4-1.7 | | | | |
| Indoor Cell Width | 2.2 | 3 | 6 | | | | |
| Outdoor Cell Width | | | | 14 | 16 | 18 | 21 |
| Outdoor BB Spacing | | | 3 | 4 | 5 | 6 | 10 |
| Outdoor BB Height | | | 7.5 | 10 | 11 | 14 | 26 |

**There are different special cases where such dimensions may be varied for safety design as seen in Table 5-5. This means that more spacing can be implemented while the opposite is forbidden.**

**Table 5-5: Cell Dimensions, (m)**

| Voltage (kV) | 35 | 110 | 150 | 220 | 330 | 500 | 750 |
|---|---|---|---|---|---|---|---|
| width | 6 | 8 | 11 | 15 | 22 | 30 | 41 |
| length | 40 | 60 | 80 | 90 | 120 | 160 | 280 |

**Similarly, the standard dimensions for the stations such as substations in the indoor style are indicated in Table 5-6.**

### Table: 5-6: Standard Dimensions of Indoor Sub Stations, m

| Voltage (kV) | Transformer rate MVA | Out going lines | Station Dimension, m. m | Weight without transformers |
|---|---|---|---|---|
| 110/35/6-11 | 1 x (5.6-20) | 4x(6-11) + 2x35 | 30x35 | 35 |
| 110/35/6-11 | 2 x (5.6-20) | 8x(6-11) + 4x35 | 34x57 | 35 |
| 110/6-11 | 1x(5.6-15) | 4x(6-11) | 20x27.5 | 18 |
| 110/6-11 | 2x(5.6-15) | 8x(6-11) | 27x35 | 37 |
| 35/6-11 | 1x(3.2-15) | 4x(6-11) | 12x14 | 15-20 |
| 35/6-11 | 1x(0.56-3.2) | 4x(6-11) | 12x14 | 10 |
| 35/6-11 | 2x(0.56-3.2) | 8x(6-11) | 14x20 | 14 |

**The parameters for indoor Distribution Stations (Main – Secondary – Terminal) can be delivered as shown in Table 5-7 where dimensions are given in cm.**

### Table 5-7: Indoor Stations Parameters, (cm)

| Voltage (kV) | 3 | 6 | 10 | 20 | 35 | 110 | 150 | 220 |
|---|---|---|---|---|---|---|---|---|
| Calculated minimum spacing between phases | 7 | 10 | 13 | 20 | 32 | 100 | 140 | 200 |
| Calculated minimum distance between a phase and ground | 6.5 | 9 | 12 | 18 | 29 | 90 | 130 | 180 |
| Practical (standard) spacing | 20-30 | 25-50 | 30-70 | 50-70 | 50-70 | 125-160 | 200 | 300 |
| Minimum distance from conductors to the wall | 9.5 | 12 | 15 | 21 | 32 | 93 | 133 | 183 |
| Minimum distance to adjacent circuits | 16.5 | 19 | 22 | 28 | 39 | 100 | 140 | 190 |
| Height of non-energized parts to adjacent circuit | 200 | 200 | 200 | 220 | 220 | 290 | 330 | 390 |
| Height of non-energized parts to ground | 250 | 250 | 250 | 270 | 270 | 340 | 370 | 420 |
| Minimum Distance of entrance to ground | 450 | 450 | 450 | 475 | 475 | 550 | 600 | 650 |

**Also, for the outdoor stations the above given parameters may be tailored as listed in Table 5-8 where the dimensions are pointed in cm units.**

## Table 5-8: Outdoor Stations Parameters, (cm)

| Voltage (kV) | Up to 10 kV | 20 | 35 | 110 | 150 | 220 | 330 | 500 |
|---|---|---|---|---|---|---|---|---|
| Calculated minimum spacing between phases | 22 | 33 | 44 | 100 | 140 | 200 | 280 | 420 |
| Calculated minimum distance between a phase and ground | 20 | 30 | 40 | 90 | 130 | 180 | 250 | 375 |
| Practical (standard) spacing (Worst conditions) | 40 | | 100 | 140-190 | 200-300 | 250-400 | | |
| Practical (standard) spacing (natural conditions) | 40-60 | | 120-200 | 200-300 | 350-425 | 350-500 | 450-600 | 600-700 |
| Minimum distance from conductors to the wall | 95 | 105 | 115 | 165 | 205 | 255 | 325 | 450 |
| Minimum distance under conductors to transported objects | 95 | 105 | 115 | 165 | 205 | 255 | 325 | 450 |
| Minimum distance from energized conductors to the isolated parts | 95 | 105 | 115 | 165 | 205 | 255 | 325 | 450 |
| Minimum height to adjacent circuits (Above or Under) | 95 | 105 | 115 | 165 | 205 | 300 | 400 | 500 |
| Entrance to ground with sever conductors swing | 290 | 300 | 310 | 360 | 400 | 450 | 520 | 465 |
| Distance between conductors of different circuits | 220 | 230 | 240 | 290 | 330 | 380 | 450 | 575 |
| Distance between energized & non operating conductors of different circuits | 220 | 230 | 240 | 290 | 330 | 380 | 450 | 575 |
| Height from energized condu-ctors to upper connections | 220 | 230 | 240 | 290 | 330 | 380 | 450 | 575 |
| Distance between energized conductors & Buildings | 220 | 230 | 240 | 290 | 330 | 380 | 450 | 575 |

**The measuring instruments have been collected for the design purpose to facilitate the mission of designers as we can see in Table 5-9 the global dimensions for the ins tallation of measuring instruments begging with the voltage of 10 kV up to 500 kV.**

## Table 5-9: Standard Dimensions For Measuring Instruments, m

| Parameter | 10 (kV) | 35 (kV) | 110 (kV) | 220 (kV) | 330 (kV) | 500 (kV) |
|---|---|---|---|---|---|---|
| CT Diameter | .2-.35 | .3 | | 1.2 | .1 | |
| CT Height | .412.9 | 1.1 | | 3.6-5.3 | 4.9 | |
| Base Dimension | .25-.4 | | | 1.3x1.4 | 1.2x1 | |
| PT Diameter | .1 | .15 | .4 | .5 | .5 | .6 |
| PT Height | 2.3 | 2.5 | 3.3 | 3.8 | 5.3 | 7 |
| PT Ring Diameter | | | | 2.2 | 2.4 | 2.6 |
| 3 Pole PT Tank Height | 3.4 | 3.5 | | | | |
| Base Dimension | | | 1.2x1.2 | 1.3x1.3 | 1.4x1.4 | 1.9x1.8 |

It would be mentioned that the 3 pole PT can be installed only for low voltage as it is seen from Table 5-9.

## 5-4: Auxiliaries

In a Power Station there are more loads than that for a substation because of the pert of generation ( electric or mechanical part of the station). Ti reflects a new added loads in the single line diagram. Such loads in power stations contain:

### 1- Pumping

There are many types of loads of pumping which is always necessary for either power or sub stations. In the power stations the pumping branches would be greater since a fuel and its requirements of devices will be added. Then, some of these loads may be indicated in the following paragraphs.

#### a) Water pumping

There are two types of water pumping according to the application as:

For transformer cooling if the power is high.

For water in boilers to generate the steam needed for turning the turbines in thermal power stations.

#### b) Fuel pumping

It is important to transmit the fuel from the storing place to the boilers in stations so that a pump could be a good tool. The rating of pumps must be large and consequentially a higher voltage would be the solution at the levels of 6.6 kV or more.

#### c) Oil Pumping

This item appears with the large capacity power transformers if the transformer oil is used. These pumps circulates the oil inside the transformer tank in order to increase the efficiency of cooling for the winding of the transformers.

### 2- Lights

Lights in a station should be tailored into two types:

#### a) Ordinary Type

This type of light is the normal known one which is applied for steady operation conditions. It may contain the lights inside and out side in the outdoor or the indoor cells or the control room and others. The supply is AC source and the distribution must cover all places either important or not. The main places may be the control room and where measuring by hour is taken.

#### b) Emergency Light

This type will be very important for the station at faulty conditions so that it must be supplied from a DC supply. The capacity of emergency light must be 10 % of the normal AC light at the places where the work will be needed if a fault occurs. All these items should be introduced in the cost processing in the design computations. Lamps must be distributed in battery and control rooms as well as in other important places such as compressors, .. etc. The final results of calculations would be tabulated as explained above.

### 3- Rectifiers

The DC station inside the electric station is a vital supply because it covers the tripping process either a limited or an overall tripping for all components of the station. This means that this station must and must cover the faulty tripping 100 % quality at the any bad condition. So, a battery station is built but it is individually not enough. Then, another back up supply should be introduced such as AC / DC rectification style. Thus, the rectifier station will be a link between both AC and

DC batteries. It may be used in the normal conditions to supply the protective devices and systems through the rectifier not the batteries. The saving for the batteries will be achieved while this rectifies will charge the batteries continuously as a trickle charger. When the AC supply cut off, the DC supply will take the responsibility to supply the tripping circuits. The importance of DC leads us to put a third supply as the AC motor / DC generator set in order to transform the AC into a DC. It is a confirmation technique for the serious cases. The number of batteries and their connections would be based on the maximum required current by the full load of the protective network in the station.

### 4- Heaters

Mainly in power stations, the fuel may be a cock or liquid with high viscosity factors so that a tool for its liquidation process may be necessary. This to make the pumping process easier as well as we need the heating effect to modify the heat transfer processing and to raise the thermal efficiency even for all types of fuels.

### 5- Air Compressors

In the case of Air blast CB, a station for the air generation will be needed. The design of the compressed air station with its piping to both levels of voltage or more could be determined according to the layout of the electric station. It is shown in Fig. 5-9 that the compressors are installed in the mid place between CB of both sides. Assuming that the capacity of air of the HV CB is 3 times that of the LV CB, we can determine the best allocation for the compressors. It should be mentioned that the generated air will be at a higher pressure ( approximately twice the required rated pressure for the CB ) and consequentially a reserve compressed air will be available. The allocation depends simply on the air distance to travel. If the distance between CB of both sides is d and the compressors should be allocated in between at a distance x from HVCB site, the volume of air required for each LVCB may be supposed as V and so for the HVCB will be 3V.

For simplicity the CB in each side may be transformed into an individual CB as given in Fig. 5-10. The equivalent single HVCB will be put at the midpoint between both terminal CB as shown in Fig. 5-10. Similarly, the equivalent single LVCB will be at the midpoint between the extreme ones. Then, the volume required for the both deduced CB (Fig. 5-10) will be n V and N (3V) for LV and HV respectively.

Then, the distances must be proportionally measured with transmitted distance as:

$$N (3V) / n V = x / ( d - x ) \qquad (5\text{-}11)$$

Where

N is the number of HV CB

n is the number of LV CB

Thus, the distance x can be determined as:

$$x = 3dN / (n+3N) \qquad (5\text{-}12)$$

The exact allocation of BC in both sides has been neglected because not only the final result will not be highly affected, but also the approximation in the actual implementation would be considered.

In the given example there are 15 and 8 CB in LV and HV sides, respectively. If the distance between both side d is 100 m, the variable x will be

$$x = 3(100)(8) / (15+3 \times 8) = 2400 / 39 = 61.5 \text{ m} \qquad (5\text{-}13)$$

It is clear that the BT has been considered in the calculation exactly.

### 6- Control Room

It is one of the most complicated item in the design of a station due to the contents inside. These contents may be indicated shortly as:

### a) The main Board

It contains the complete single line diagram with the ability of switching from it. The status of CB is indicated always and it illustrates any abnormal operations or faults. This is the large type of boards while there are many other small for different purposes.

### b) Automation

The principle of supervision may be designed either Half or Full automated with a continuous dispatching control. Also, the modern types of station permit the application possibility of Internet Concept.

### c) Indication Applications

All measuring instruments are installed to read in the control room mainly but the horning and flickering concepts must be the basic rules for the supervision goal. The continuous readings can be implemented in the control room but the minor readings can be at the site of the element in the cell. All major indicators must be in the main boards of the control room.

### d) Synchronism

A major switch board is the synchronizing board which is the common tool for the switching on of any part in the station to the other or any part in the station with the network. It depends on the three factors ( Voltage, frequency and phase sequence) to synchronize the connection and to ensure that both sides before connection can be connected.

### e) Lay Out of The Control Room

It is easy to understand the lay out of a control room as it represents the station to a certain scale. The main board should be at the front where other boards will be behind (Fig. 5-11) . It is shown that a board or more represent a cell as a minor board while the main board contains the indication for any board inside the control room.

### f) Fire Fighting

It is very important to be installed and it must be checked regularly to ensure the security and safety of the station. It always works automatically according to the specification concerning the environmental rules. There are two main concepts for such item as the $CO_2$ or the spray of water. The automatic operation is the best.

### 10- Others

All other loads either personnel or that for a device or equipment may be included in the SLD of the distribution pert in the station. These elements are explained with the chapter of SLD before. Earthing can be an important item in this case to protect both human and equipments against touch voltage.

## 5-5: Economic considerations

The engineering design of a station is based mainly on the economic principle that means the most practical with highest quality. This highest level may be very expensive so that we must choose the !00 % solution or the nearest one with the minimum cost. Such choice should have all technical and engineering requirements without any loss in the major performance. So, the economic consideration would be a design factor for either the manufacturer or the designer. This may be also, the foundation for the calculations of tenders by the contractors or even for the receipt process by the authorities or companies in concern.

## 1- Basics

**In the marketing field the price of a product depends on both offer as a supply and need (buying) in order that the price of a product will be dynamically varied. It is not the unique reason for such change but the inflation rate enforced the market to raise continuously the price. Thus, the cost could be subjected to any changes as a function of time. Therefore, the cost of a project in general should be evaluated for a specified short term of time. This term may be considered as 3- 6 months according to the state. The supplier must implement all his works on the basis of a schedule to avoid himself from the penalty rules. Any contact for a project should have a determined requirements as:**

### a) Schedule

**It is an application that put the time of pay and that for supplying the devices and equipments. The installation limit time must be indicated. The time of testing, training, spare parts supply, guarantee and the penalty points with respect to each item.**

### b) Penalty System

**This factor limits any relaxation in the implementation of a contract and to ensure the best work level. It includes not only the late applying but also the concept of completing the work if the contactor is stopped.**

### c) Financing supply

**The local law controls this item such as the percentage financing supply during the implementation of the work. Also, the insurance back up principle would be pointed from the beginning.**

### d) Specifications

**The standard specification must be clearly indicated either from the technical or engineering point of view. The high quality may be a positive requirement in spite of the un-concrete values instead of the exact digits. This opens the market in the front of the suppliers. The standard specifications should be determined according to the international standards to be not suitable for a certain manufacturer or a single producer. This must be in a range of standards to give the chance for a lot of producers to enter the process of application as well as it will get you able to choose the best tender between all. This may lead to minimize the cost proposed for a certain producer. We never cannot remember that the choice of the best technical specifications will take the priority to the head. Then, the engineering requirements will appear as the boundaries of both technical and economic considerations. This requirements protect all processes in the concern such as the quality control, the modern products, the different stages of installation from the beginning to the end as it would be clear in the next items.**

## 2- Cost of Elements

**A station consists of different cells, auxiliaries, devices, equipments and others so that its bulk cost begins at the first element in any device. We should propose the rang of its price during the period from the time of costing to about one year later. This because the decision cycle may consume half a year and then the marketing study would be a major item. This idea can be translated automatically into a cell price, devices, transformers, alternators, ... etc. Thus, engineers would tabulate these results of marketing to make it easy for designers or the workers in that field. Therefore, tables for each element must present the price growth each time term as shown in Table 5-10. This table may be tailored for many manufactures or countries according to the quality level must be achieved.**

### Table 5-10: Element Price in the market in Germany for example ( units L. E. or $ or others )

| Element | 1 year ago | now | 6 months later | 1 year later |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Updating for such Table may be very important to facilitate the process of costing when required. From such concept another Table can be deduced as given in Table 5-11.**

### Table 5-11: Cell Price according to the voltage level.

| Voltage level, kV | 1 year ago | now | 6 months later | 1 year later |
|---|---|---|---|---|
| 11 | | | | |
| 66 | | | | |
| 220 | | | | |
| 330 | | | | |

**This table would be repeated for other contents such as alternators, boilers, transformers, ... etc.**
**Otherwise, the pricing may be preferred to be classified according to the type of the part interested such as:**

#### a) Electrical Cost

**In this section the elements will be that of the electrical parts of the contents and then a cell can be evaluated as given before.**

#### b) Civil Cost

**There are many important works such as portals and foundations of the electric components such as isolating link, CB or CT and VT, ... etc. Also, the earthing ground under the land surface can be sectionalized into the electric part and the civil works accompanied with it. This is an example besides many other application such as the rail ways required for the transformers and others.**

#### c) Mechanical Cost

**In this section the compressors, boilers, loading of different components during the work may be the aim and thus, their evaluation and tabulation can implemented individually such that of the case of civil parts and electrical ones.**

**d) Cost of Auxiliaries**

**The pricing of auxiliaries in a station may be very important because it takes a suitable finance in the station cost in spite of its low percentage in the overall pricing. It appears to be more difficult because it contains many items. They also may cover electric, mechanical, chemical, civil styles and more so that they would be importantly introduced and all prices related can be also tabulated.**

## 4- Working Operation Requirements

**The above items considered reflect the shown materials for pricing but there are different costs that takes a lot of the total cost. This item related to the different stages of installation to safe the equipment and worker against hurts. They may be shortly indicated as:**

### a) Storing

**The storing of the products from the beginning till the final installation is important because it should be safe from stolen or damage. Any possible danger must be avoided and the schedule of transportation relative to that of installation would be synchronized to cover such cases. The places of storing must be in a good suitable weather. Different measurements can be checked always to protect them inside the site of storing**

### b) Transportation

**The process of transportation of the big equipment such as transformers and alternators of large electric stations provides an attached requirements for the implementation. It includes the technology of shipping and lifting such elements from the ground to above the transmitters and then to lay them again to the ground either at sores or at the site itself directly. This stage is not appeared materially but it consumes a lot in the cost of a station due to the need for experts in the supervision of the steps of transportation. In some cases, the Hydrogen may be a tool for the storing and so, a danger would be taken into consideration.**

**The modern technology makes this process may it more easier but the risk factor must be introduced the design Tables. Thus, a table for the transportation must be prepared regularly. It should be indicated that the price growth will be slower than the for devices and elements.**

### c) Training

**One of the most important factors in the evaluation of a project is the training style and its level because this training reflects the level of operation of a station. This means that good training will be a positive to protect a station and to maintain it for a long time. This training can be transferred into money to be added to the list of costs of a station. It can also, be tabulated with different levels of training and the number of trained persons as well as their educational level.**

### d) Testing

**The receipt process is the good tool as it gives a measurement qualified for the decision of receipt of a station. Testing here can be stated as a specification title because it should be carried according to the technical specifications. The final decision for the receipt will mainly depend on the testing results. The consumption of time and tools may be transferred into money so that it may be tabulated as a product as explained above.**

### e) Guarantee and Maintenance

**Finally the grantee as well as the maintenance would be a technical condition to safe the station against the quality of components, This means that the period of maintenance after the final receipt would be a differential factor in the final**

decision when a person evaluates the project. It also, can be tabulated as a cost value like other components discussed before.

The final cost would be tabulated as given before to gather first each item and then for each level of voltage. This can be expanded to gather the cost for a station as a Whole such as equipment and then as a summation of equipment and the last factors in the section of cost of working operations. This means that the costing process is a cascading style phenomenon.

## 5-6:Problems

1. Evaluate the area of a 220 kV cell for a transformer in a station.

2. Compute the different heights for the trusses in a normal 110 kV transmission cell

3. Deduce the different levels for the HV wires in a transformer cell at 110 kV and then compare the results with 220 kV cell.

4. Find the ratio between corresponding heights for both levels of a 132/500 kV transformer cell.

5. Determine the ratio between maximum wire heights for a transformer and a potential transformer 110 kV cells in a station.

6. Get the percentage increase in the maximum wire height for a 66 kV transformer cell and Bus tie cell on the same bus bar.

7. Deduce the ratio between the maximum wire height for a transformer 400 kV to that of a Bus coupler cell in the same yard.

8. Compute the percentage increase in the height of trusses in the transformer 220 kV cell if the reverse return style is applied.

9. Calculate the saving in the area of a transformer cell if it is based on the reverse return style with respect to the sequential type connection.

10. In a 132 kV yard of a substation, there are 14 cells as: (2 transformers, 2 Bus coupler, 2 bus tie, 4 potential transformers and 4 lines. Calculate the percentage saving area in if a transformer cell is based on the return reverse style in the cell connection.

Derive the saving in the station area if the potential cells are reduced to only two cells.

11- Design the bus bar section for a 500 / 220 kV step down transformer of 130 / 120 MVA, which is feeding 4 x 30 MVA, 220 kV, transmission lines. Give the wiring and mechanical calculations if the maximum allowable tension is 20 000 Ib. The spacing between phases may be 6 m and the 20 kV cell width may e of 18 m.

12- Design the single line diagram for two different distributions in the above problem 1 and deduce the distribution of currents in branches as well as the distribution of node voltage in the connection scheme in each case.

13- For the above problem check the corona effect and redesign the wiring diagram if needed and the rupture capacity of line circuit breaker. Assume any additional data to find the requirements.

14- In the above problem 3 if the double B.B. system is used, find the total cost of such a part in the station installation. Assume that the CB cost is 70 times that of isolating link. The conductor costs 10 L.E./ m, insulator 100L.E./ dish and you can suppose the other prices. Give your calculations in details.

15- Write a computer program to design a section as in the problem 11.

16- Calculate the complete cost for the equipment and materials used in a power station containing:

2 x 400 MVA alternators, 33 kV ,7 x 10 MVA feeders, 33 kV

6 x 120 MVA, 33/220 kV transformers , 18 x 40 MVA, 220 kV lines

**2 x 5 MVA, 33 / 11 kV auxiliary transformers.**
**Tabulate all results in details**
**17- Put the details of calculation for a tender to install the above station if the land costs 1000 L.E. / $m^2$ & you have the following:**
**Price of CB = (kV) $e^P$ + A**
**Price of Isolating Link = B (kV) + C**
**Price of trusses = D (kV) + E**
**All constants are tabulated below:**

| Voltage | A | B | C | P | D | E |
|---|---|---|---|---|---|---|
| 220 kV | 10 000 | 100 | 1000 | 100 | 100 | 15 |
| 33 kV | 2000 | 100 | 10 | 10 | 100 | 10 |
| 11 kV | 1000 | 10 | 100 | 5 | 500 | 50 |

**18- In the above problem, derive the percentage saving in cost if the area distribution is based on horizontal installation for a cell instead the vertical one.**
**19. Evaluate the area of a 220 kV cell for a transformer in a station.**
**20. Compute the different heights for the trusses in a normal 110 kV transmission cell**
**21. Deduce the different levels for the HV wires in a transformer cell at 110 kV and then compare the results with 220 kV cell.**
**22. Find the ratio between corresponding heights for both levels of a 132/500 kV transformer cell.**
**23. Determine the ratio between maximum wire heights for a transformer cell and a potential transformer 66 kV cell in a station.**
**24. Get the percentage increase in the maximum wire height for a 33 kV transformer cell and Bus tie cell on the same bus bar.**
**25. Deduce the ratio between the maximum wire height for a transformer 500 kV to that of a Bus coupler cell in the same yard.**
**26. Compute the percentage increase in the height of trusses in the transformer 220 kV cell if the reverse return style is applied.**
**27. Calculate the saving in the area of a transformer cell if it is based on the reverse return style with respect to the sequential type connection.**
**28. In a 132 kV yard of a substation, there are 14 cells as: (2 transformers, 2 BC, 2 bus tie, 4 potential transformers and 6 lines. Calculate the saving in the area in percentage if the transformer cell is based on the return reverse style in the cell connection.**
**Derive the saving in the station area if the potential cells are reduced to only two cells.**

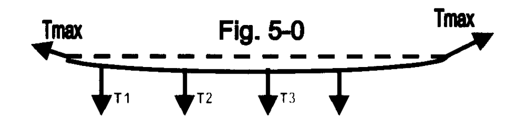



Fig. 5-0

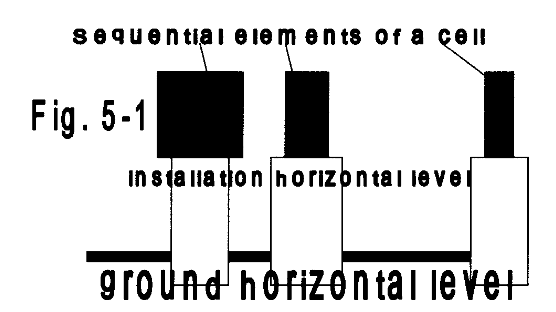



Fig. 5-1

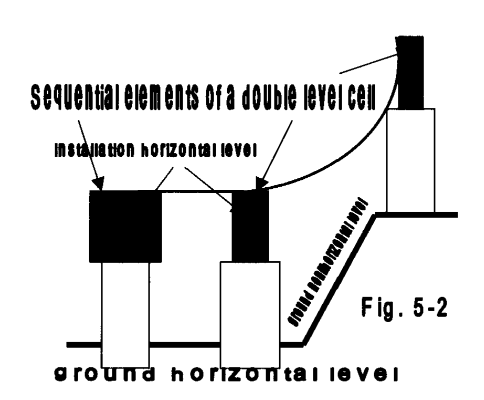



Fig. 5-2

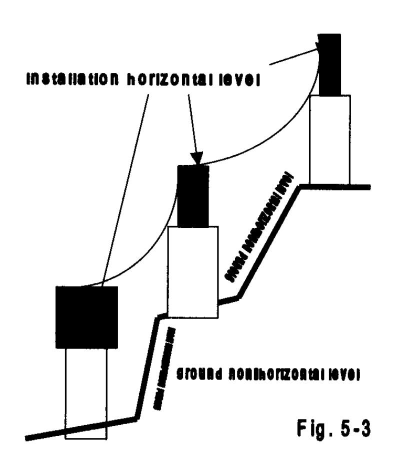



Fig. 5-3

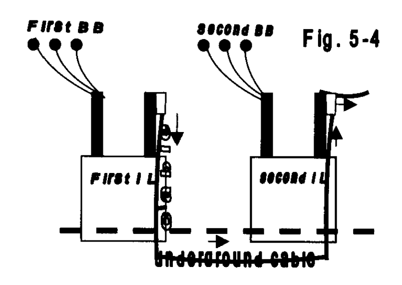



Fig. 5-4

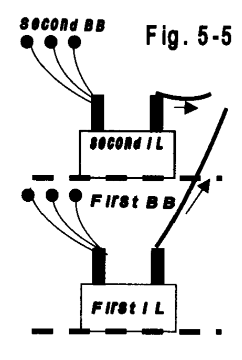



Fig. 5-5

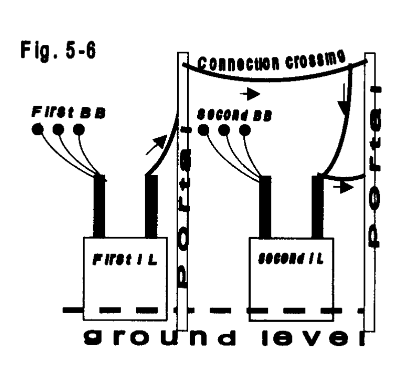



Fig. 5-6

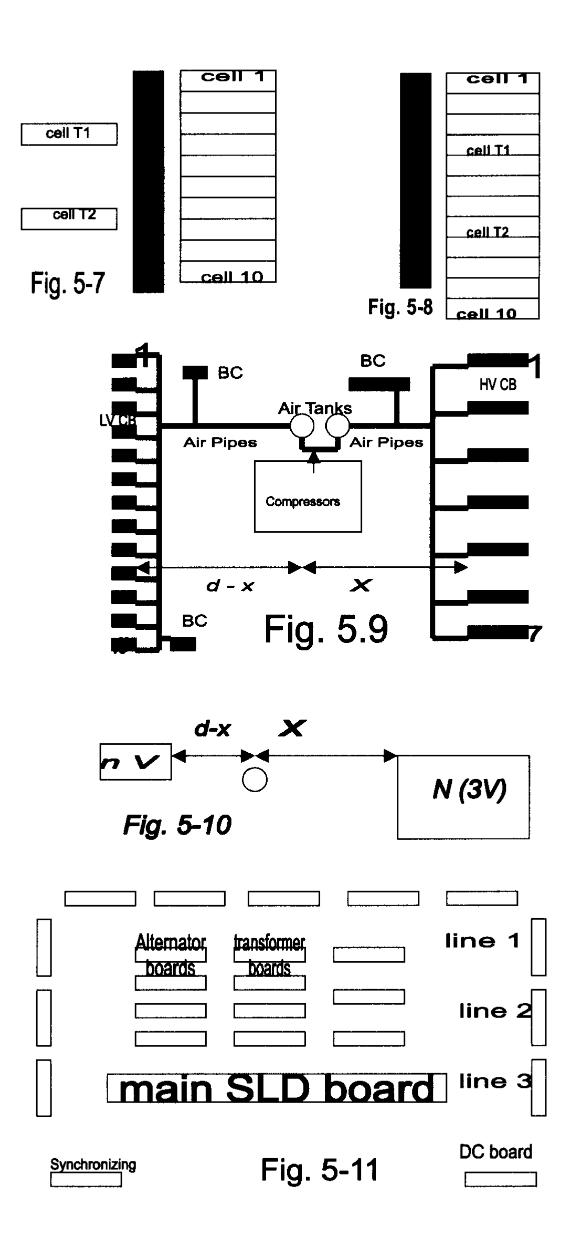



Fig. 5-7

Fig. 5-8

Fig. 5.9

*Fig. 5-10*

Fig. 5-11

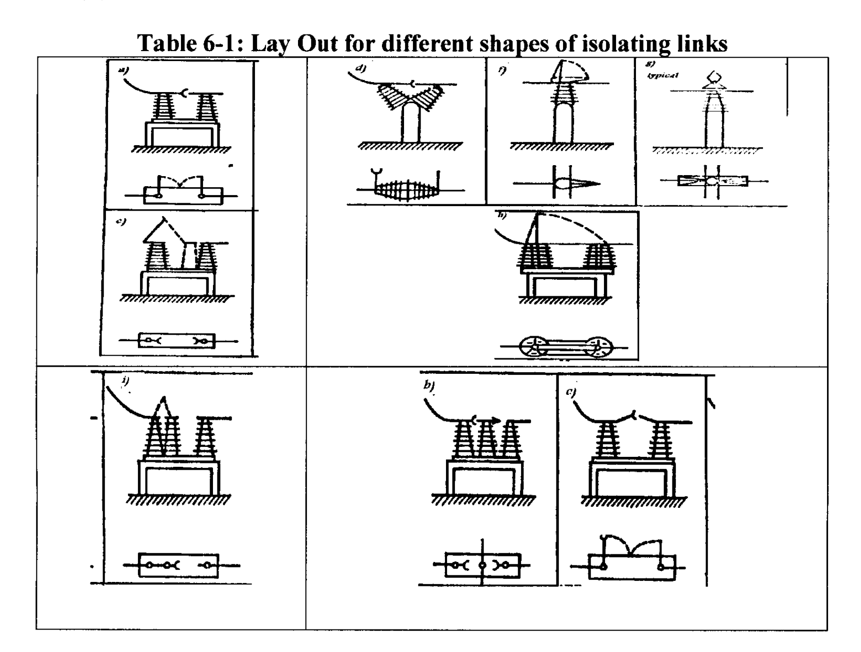
# Chapter VI
# SAMPLES

The subject of design and its explanation makes the concept more difficult due to the needed experience from practice and theory. The above chapters deal with the items of theory and basics where a lot of problem must be already achieved. Therefore, some helping tools will be aiding for the idea of the book so that some practical examples would be presented with a comment to make the subject easier. The present chapter deals with this item to cover the individual concept for the explaining. It is important to marked that the pictures in this chapter are scanned from the reference of Ousova as listed in the references at the end of the book.

## 6-1: Isolating Links

Isolating links as a shape are different but the most wide known types may be included here for illustration. This means that the presented diagrams or sections or even items are a sample of the subject as a whole. Also, various types may be studied on the bases of the given explanation so that our samples can be used as a guide for a certain subject.
The present chapter concerned with the explained already items in the previous chapters. This leads us to be sure to understand all samples which would be related with.

**Table 6-1: Lay Out for different shapes of isolating links**



## I- Different Shapes

**Table 6-1 lists the most common shape of high voltage and ultra-high voltage level isolating links for both elevation and plan so that other types would be understand without any difficulty or effort.**

## II- Horizontal moving arms

**It is said before about the variety in the direction of motion of the arms of the isolating links specially with the UHV level where the width of a cell will be greatly increased up to a value may be incredible. So, such horizontal isolating switches will be for the level of voltage up to 330 or sometimes 400 kV. Then alay out of a 110 kV isolating link (Out Door)could be drawn in Fig. 6.1 as an example for other levels of voltages.**

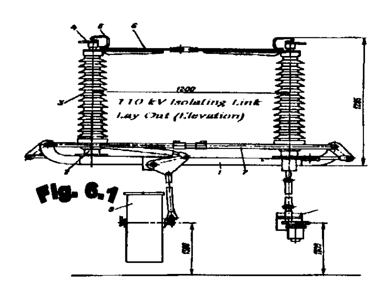



Fig. 6.1

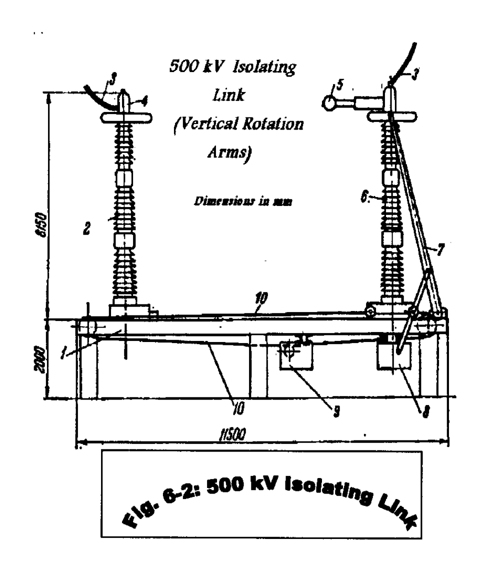



Fig. 6-2: 500 kV Isolating Link

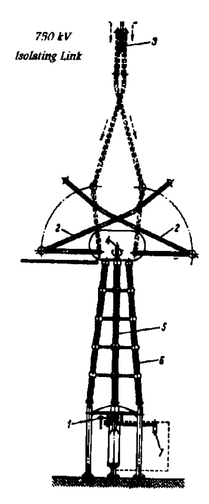



Fig. 6-3: 750 kV Isolating Link

The elevation explains the dimension ratio because this drawing is to scale. Different parts of the links are marked such as moving arm (6), supporting insulator (3), the moving metal shaft (4) ( inside the insulator support 4), that connected to the part (5) to transport the movement to the moving arms (6). This motion is transmitted through the mechanism (2) under the insulator and the control panel is numbered as 9. All dimensions on the graph are given in mm.

## III- Vertical moving arms

As the nominal operating voltage directs towards the higher, the insulation coordination will sharply raised. The UHV levels leads to a new idea about the direction of movement of the arms to be in the vertical direction. Thus, the spacing between phases and consequentially, width of the cells will be decreased with this new idea. Fig. 6-2 illustrates an isolating link for the 500 kV level while for the level of 750 kV the isolating link may be drawn as in Fig. 6-3. Otherwise, the 750 kV isolating link has arms both to be rotated in a wide angle rang in order to minimize the distances between conductors in the direction of the vertical axis. This can be shown from the figure.

## IV- Earthing Rods

The earthing presence in the site is an important and vital item to cover the protection against danger either with the respect to persons or the equipment. Then, the earthing rods are a good tool to be attached with. This tool (numbered as 10) is given in Fig. 6-2, which indicate the operating direction of such rod to make sure that the arm metal can be in a good contact to earth. Also, an interlock concept should be inserted to prevent any wrong operating step during the sequence of closing or opening a circuit in the station.

# 6-2: Actual Lay Out

Actual layout would be interest of the given item since it has been explained above. This subject includes both types of stations as power stations and substations. The last one consists of either the substation at the HV side or these stations at the distribution level or even the switching stations.

## I- Power Stations

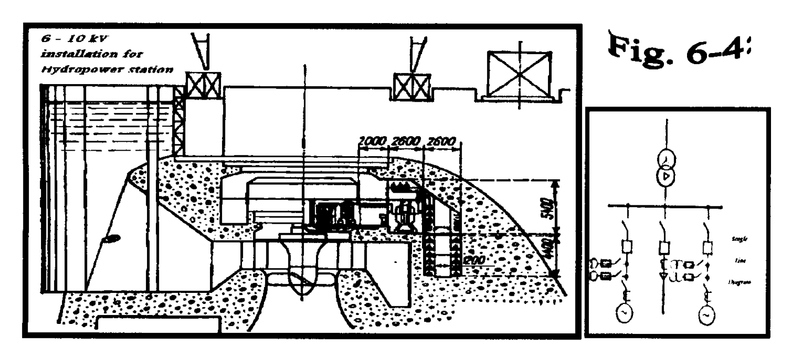



Fig. 6-4:

Real stations as a layout may vary in a wide rang depending on the type of the station. This will be clear with the hydro type power plants or that of the thermal fuel base or those with the bulk power atomic energy. The layout for both hydro-power station and the thermal stations will be presented in the next paragraphs.

## 1- Hydro-stations

The hydro power station is the most cheapest type between all and it is characterized through the multi level for the HV installations as given in Fig. 6-4.It is a typical 6-10 kV as shown in the single line diagram where triple units are connected to a single transformer.

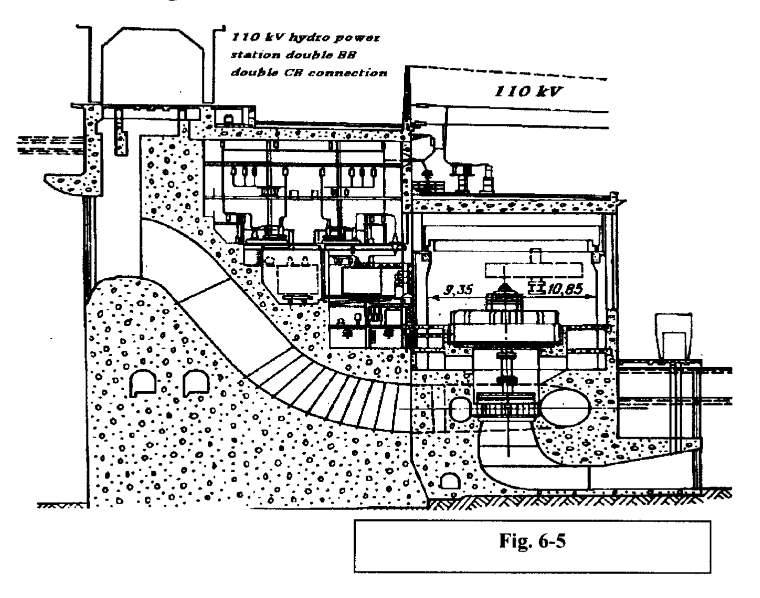



Fig. 6-5

On the other hand, Fig. 6-5 presents another shape for the 110 kV level of voltage. It is based on the double bus bar system with double circuit breaker operation as shown. With the raised voltage this layout can be shown in Fig. 6-6 for the 220 kV installation. Also, Fig. 6-7 presents the 220 kV switch yard. In this figure the overall layout for the site where the power transformer is located is shown in Fig. 6-7 (a). On the other hand the side view for such a layout may be deduced according to the power transformer shape as given in Fig. 6-7 (b).

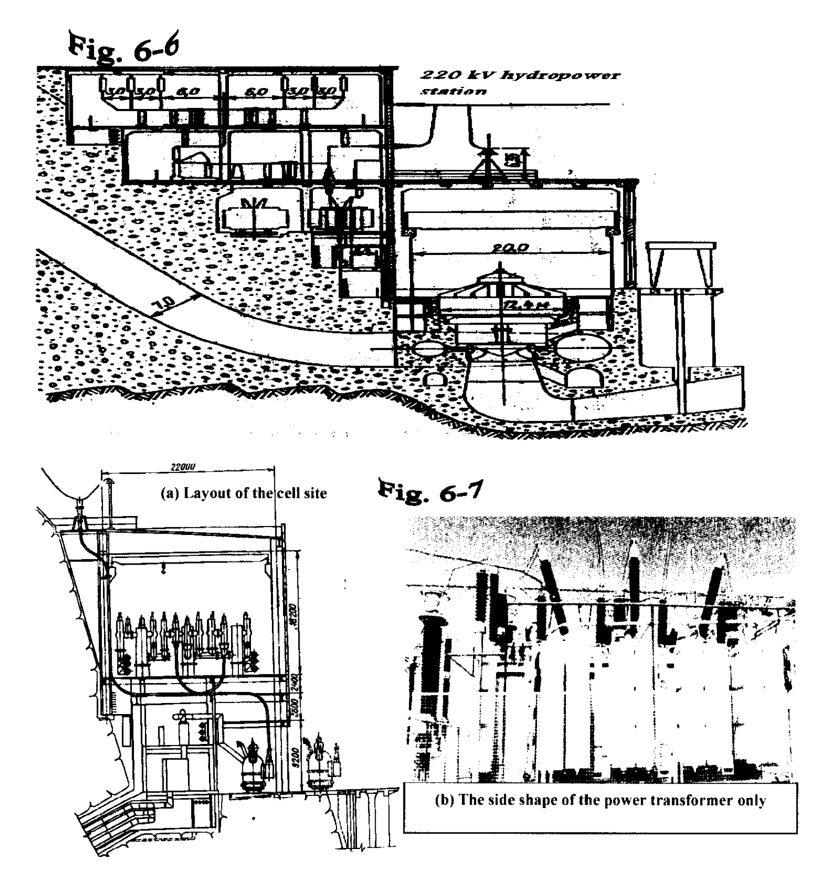



Fig. 6-6

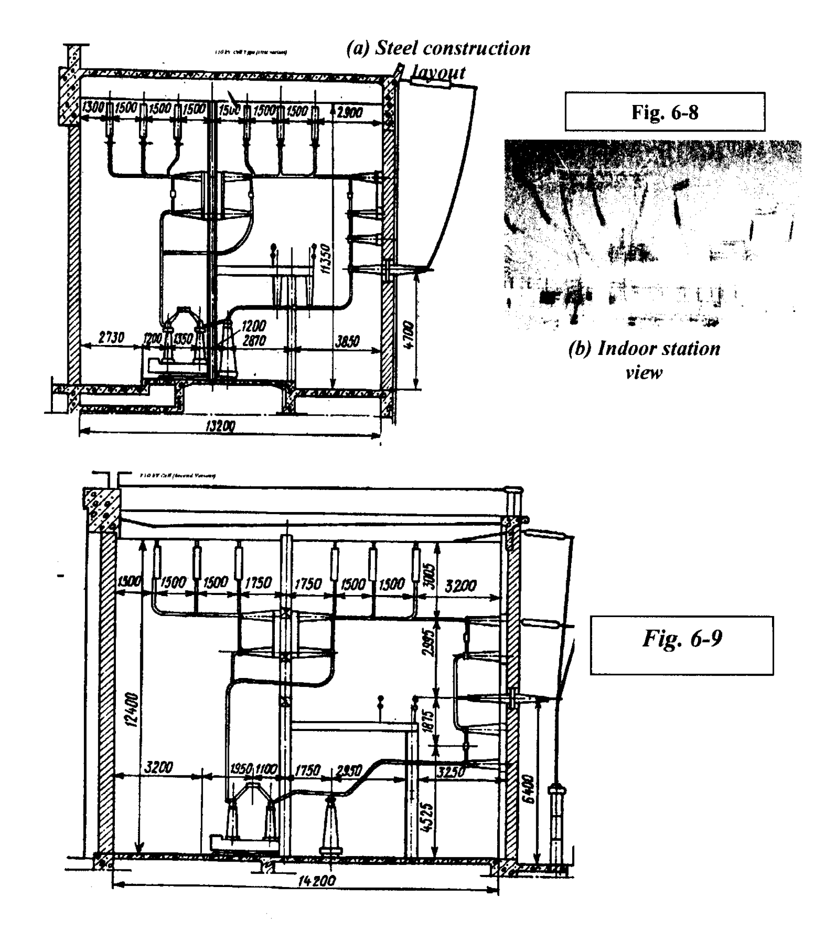
(a) Layout of the cell site

Fig. 6-7

(b) The side shape of the power transformer only

## 2- Thermal stations

Contrary for the thermal types of power station such as steam or gas power stations, the layout is typically standard shape due to the horizontal land surface. Fig. 6-8 shows the first variant for a 110kV cell while the shape of an indoor power station is given in Fig. 6-8 (b). A second connection for the said station is shown in Fig. 6-9. All of these cells are of the steel style for the portals used..




(a) Steel construction layout

Fig. 6-8

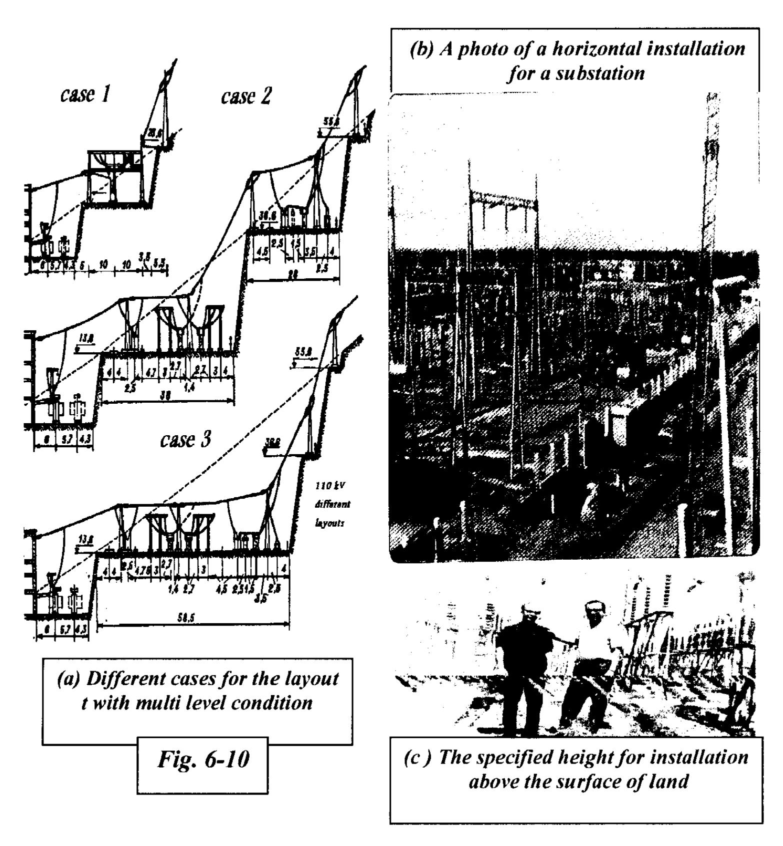
(b) Indoor station view

Fig. 6-9

## II- Substations

**Substations are most in use either in power stations or independently so that any power station must contain a substation or more inside. Then, the more understand for the substation will help in a best condition for the network as a whole. This means that the substations are widely installed in a network with respect to the power stations. They are implemented at the terminal of users as at the bus of all alternators in it besides the intermediate cases.**

## 1. High Voltage Stations



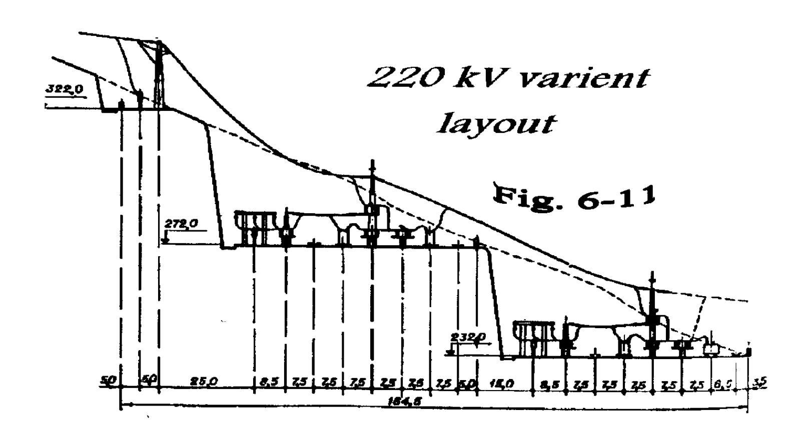

*(a) Different cases for the layout t with multi level condition*

*(b) A photo of a horizontal installation for a substation*

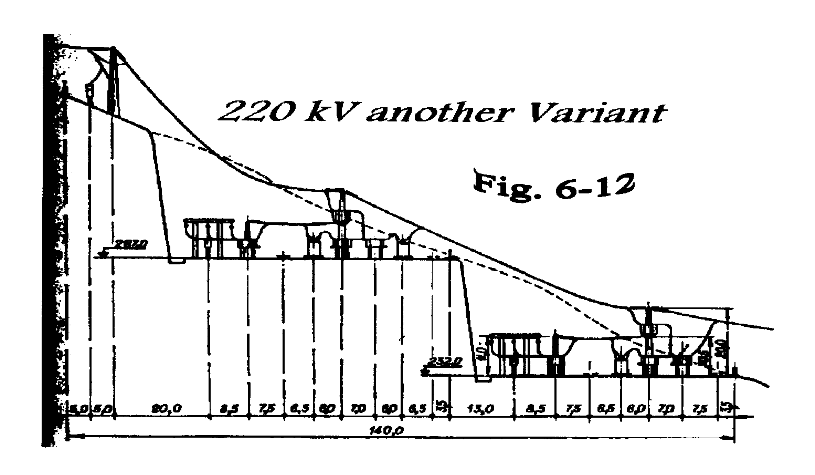
*(c) The specified height for installation above the surface of land*

***Fig. 6-10***

**In Fig. 6-10 (a) it is given a layout for the multi level installation for a station at the same voltage level 110 kV switchyard with three different variants where this condition may be appeared in the mountains or even in a new places where the land is not flat as shown in Fig. 6-10 (b).**




This explains the difficulty for the installation in different levels due to the sag variety and the specified spacing with ground as cleared from the heights above surface of Fig. 6-10 (c). The persons under the HV wires as shown will be considered in the cases of the different cases of lay out as in Fig. 6-10 (a). This also, can be shown in Fig. 6-10 (b) for the passing of cars and equipment under the wires either for installation works or the operation conditions as in Fig. 6-10 (c). In other words, Fig. 6-11 presents a case for the 220 kV installation but other shapes for the same case are given in Fig. 6-12 for example but the multi level installation is given in Fig. 6-13 (a).



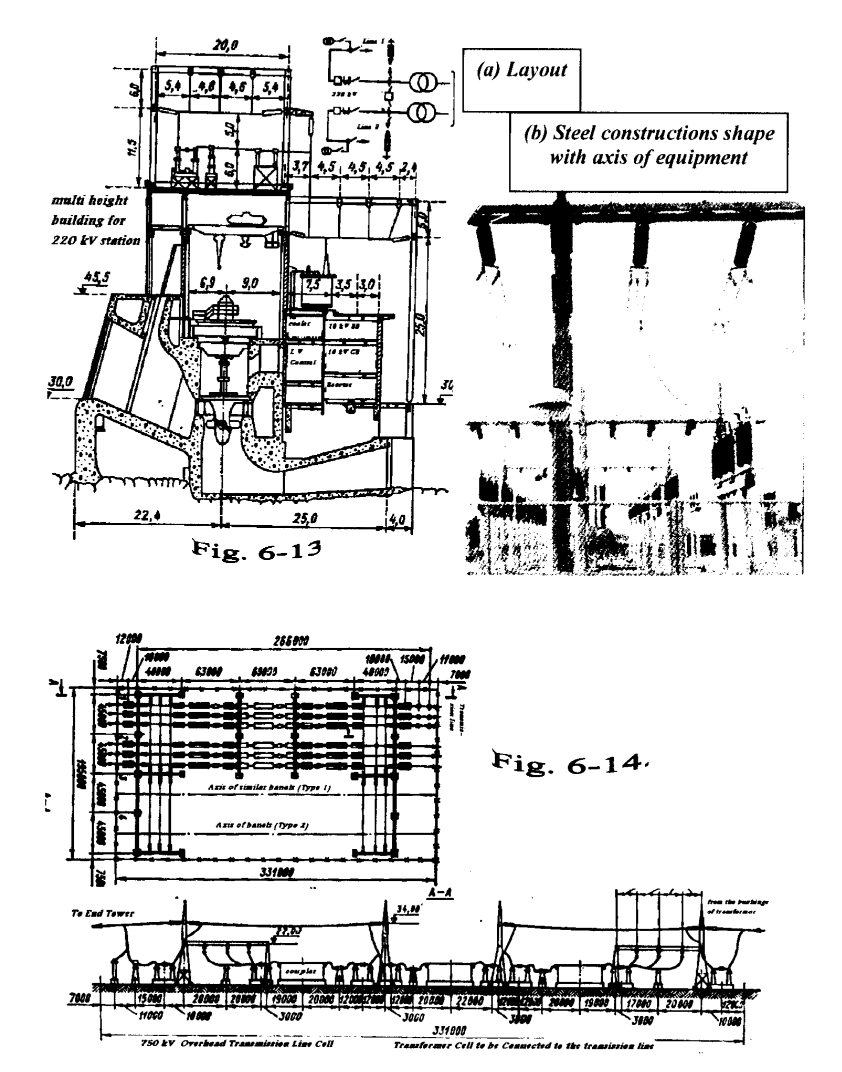
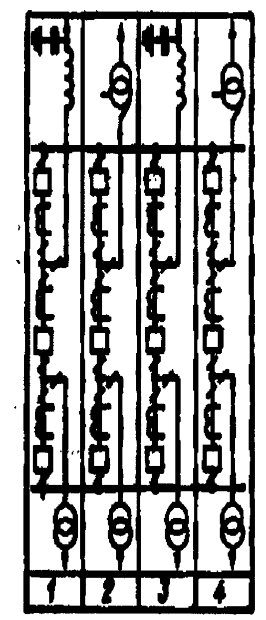



**Figure 6-13 (b) put the shape of the axis for equipment in the layout. This photograph may help well in the design of the overall of the layout for the station as a whole. Also, Fig. 6-14 and Fig. 6-15 show the first case for a 750 kV for the connection between the transformer and the transmission line and give the single line diagram for the case of single circuit breaker utilization with its lay out.**




*750 kV single line diagram*

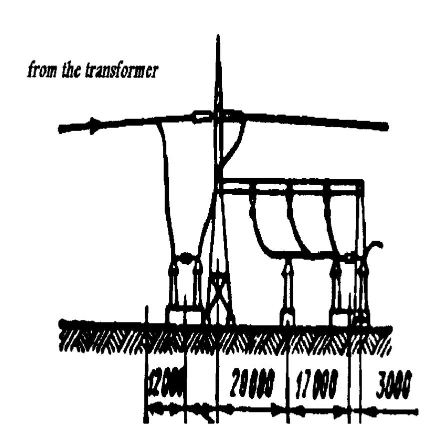
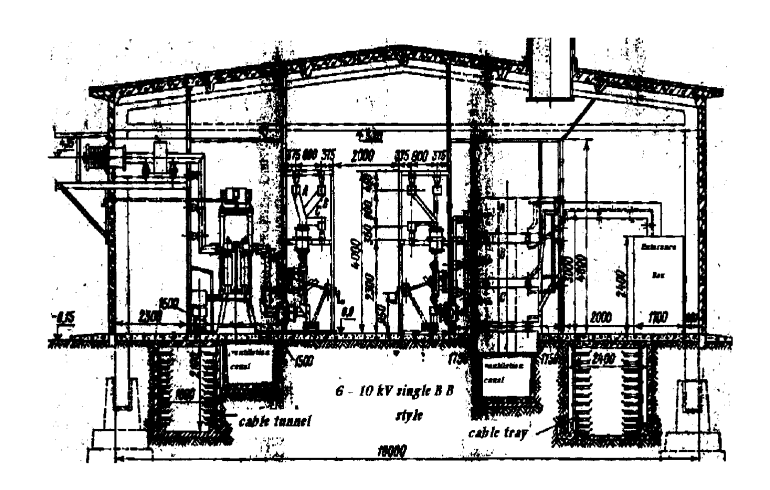



Fig. 6-15

## 2. Low Voltage Distribution Stations

**These stations can be tailored into many types but we here take such item from the point of view of actual layout as a standard performance for illustration. Fig. 6-16 draws the actual 6-10 kV single bus bar system lay out with its single line diagram but the double bus bar style has been indicated in Fig. 6-17.**



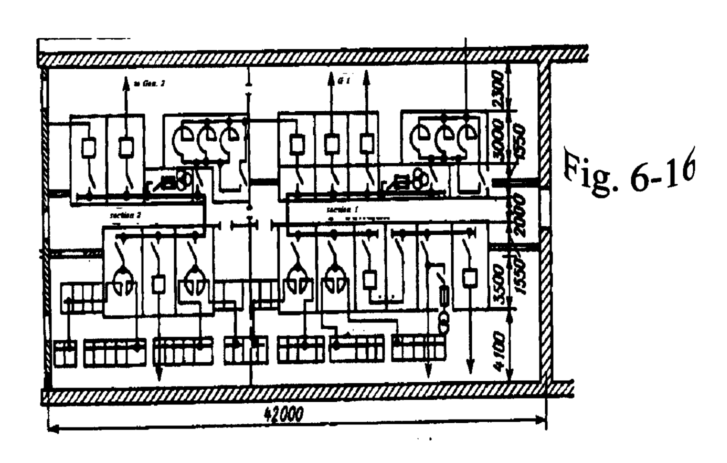




Fig. 6-16

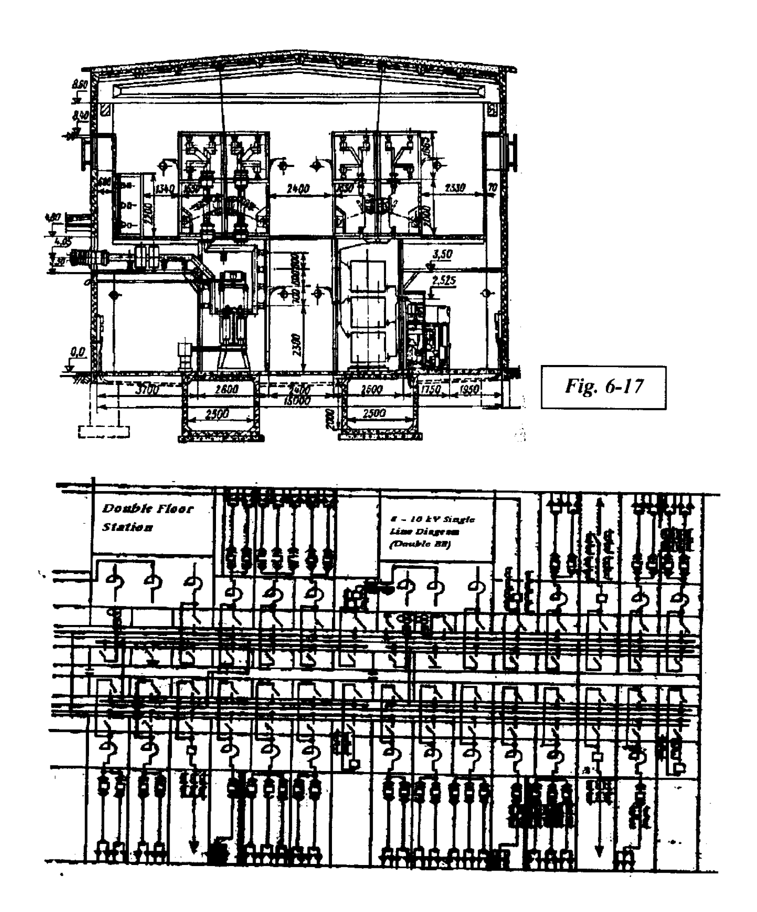



Fig. 6-17

Firstly some standard applications may be inserted here for the purpose of illustration as the different variants for the 6-10 kV installations in Fig. 6-18 and Fig. 6-19. The standard 35 kV installation is shown in Fig. 6-20.

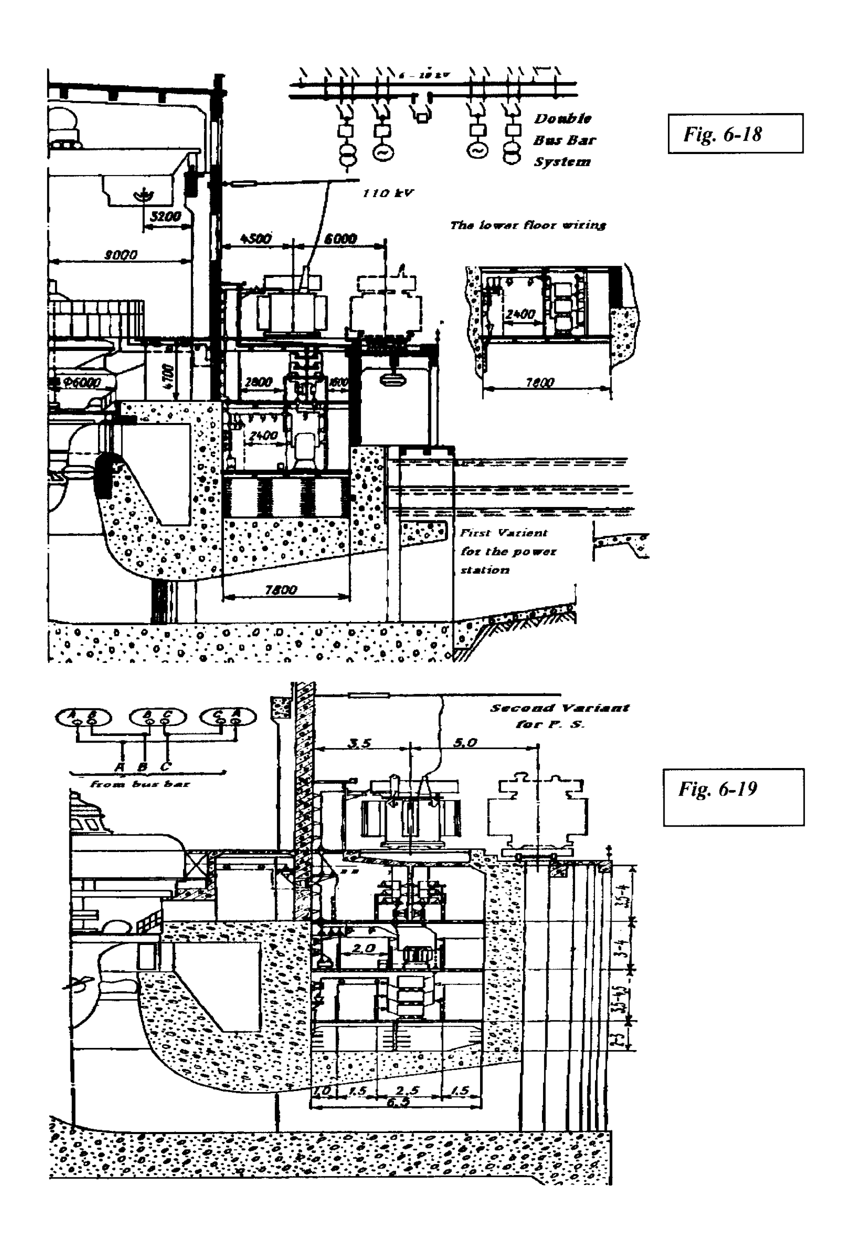



Fig. 6-18

Fig. 6-19

The indoor structures will be the main implementation in such section so that the most of them will be either a steel structure for outdoor or for building indoor style. Fig. 6-21(a) presents the steel structure type for 6-10 kV standard while Fig. 6-21 (b) gives the actual shape for such installation in general. Otherwise, Fig. 6-22 gives the same layout but for the voltage of 35 kV. In last case the general steel portal has been used.

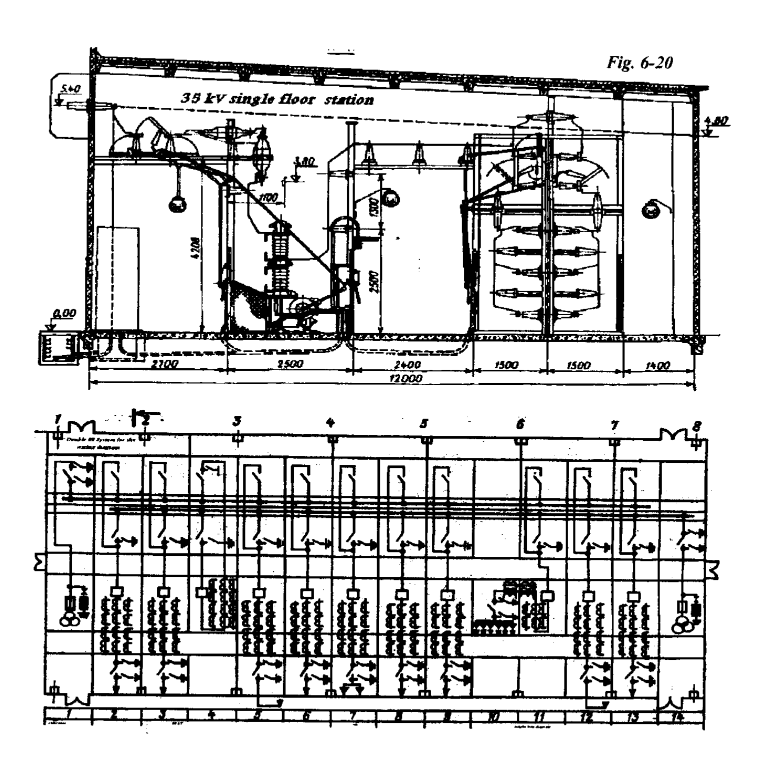



*Fig. 6-20*

## 6-3: Circuit Breaker Utilization

The isolating link can isolate a part of the network away from an another although it cannot break the circuit current. It is a tool for isolation between the life part from earthed parts, or from the other life parts, or from the non- life non-earthed sections inside the station. It is an important tool in the sequence process of switching in the station either generating or transformer station. This device is a safe one for other equipment such as circuit breaker or power transformers or measuring potential and current transformers. It is also, a main device to isolate the bus bar from cells. Its importance appears with the engineering switching processes as well as during the testing conditions and for maintenance.

The circuit breaker in a network plays a main role to keep it reliable as the interruption of the power supply at the user end is forbidden. The circuit breaker opens a circuit as ell as closes it. It has an arcing chamber in order that the sparks can be generated and then distinguished. It helps the circuit to be out of service safely. The circuit breaker costs high relative to isolating links although its use is a basic need. All projects for design in networks try to minimize the quantity of circuit breakers in the scheme with the raising in voltage. Contrary, with UHV sometimes more than a single circuit breaker base may be required to insure the reliability of operation. Thus, different connections through the single line diagrams may be tailored in the following sections.

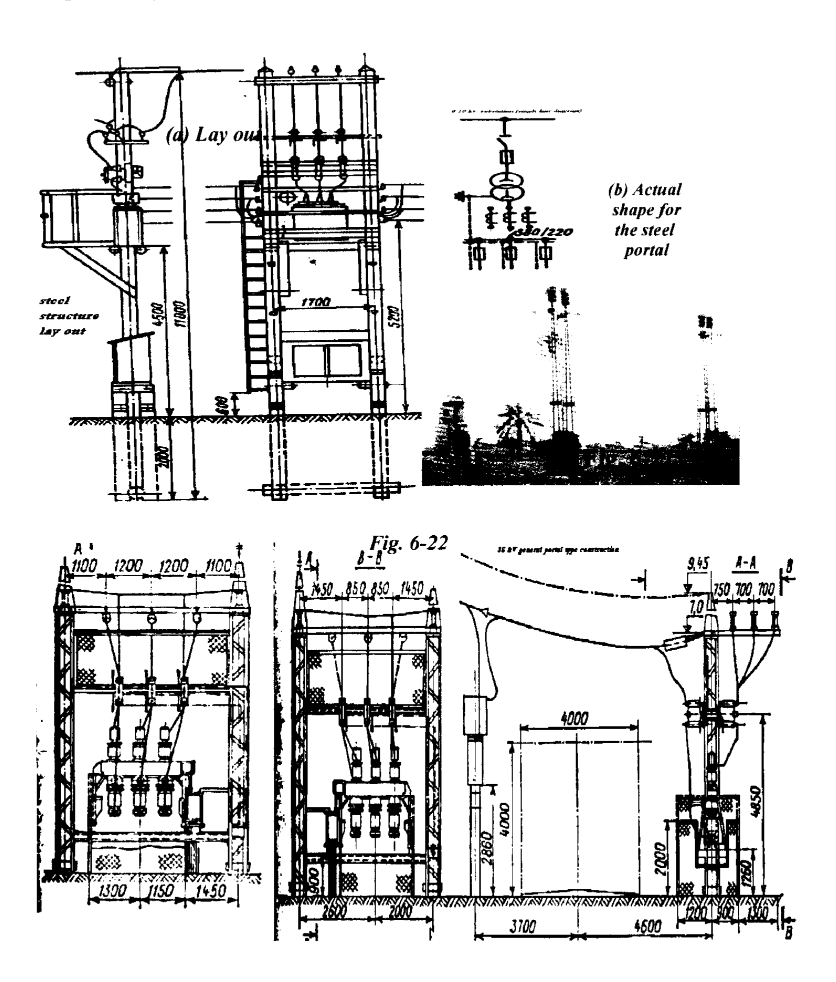
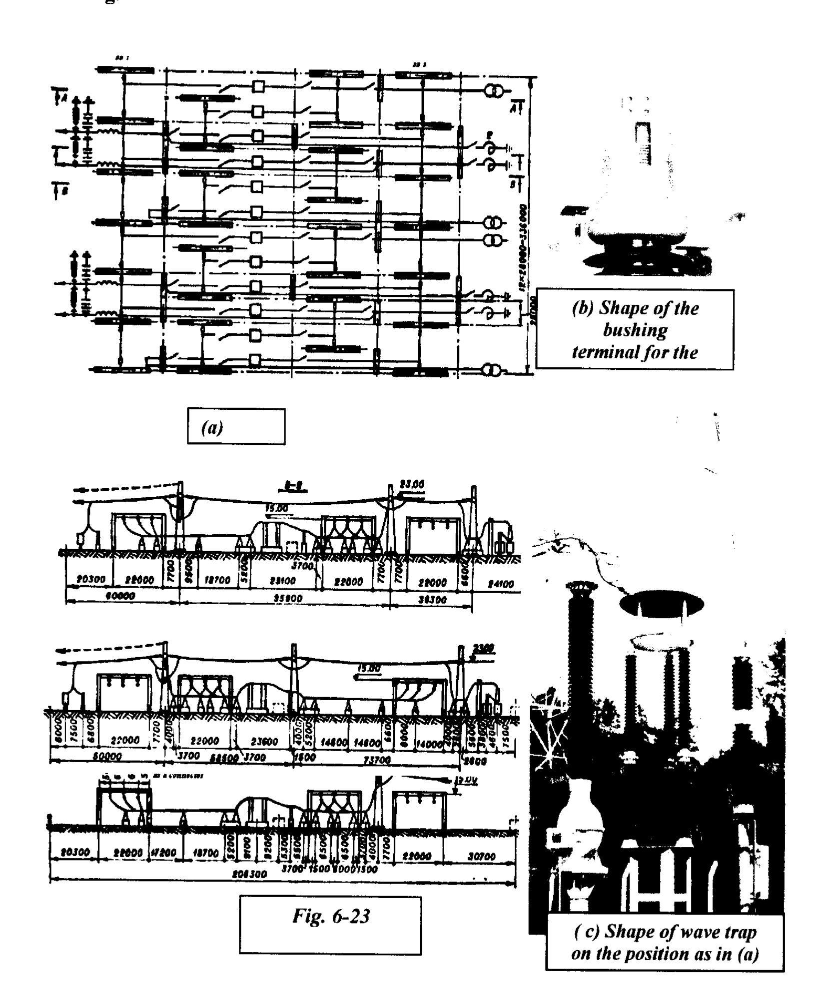



Fig. 6-22

## I- Single Circuit Breaker Connection

This technique is the most economic solution in the design due to the use of only one circuit breaker for the device or the cell as it is shown in Fig. 6-23 for the 500kV level. It should be said that Fig. 6-23 (a) is the layout concept for the item from different points but Fig. 6-23 (b) shows the terminal connection of the winding of the transformer to the wiring in the yard. This is considered in the lay out as this metal plate connector makes the connection very well. Also, the actual photograph for the wave trap may be shown in Fig. 6-23 (c ) as a view for the meaning.



*(a)*

*(b) Shape of the bushing terminal for the*

*( c) Shape of wave trap on the position as in (a)*

*Fig. 6-23*

## II- Double Breakers Function

**For more reliable schemes a second circuit breaker is inserted to be double function circuit breakers as given in Fig. 6-24 for the level of 500 kV with its single line diagram as indicated in the figure. For higher voltages the figure may be similar as in Fig. 6-25 for the 750 kV station.**

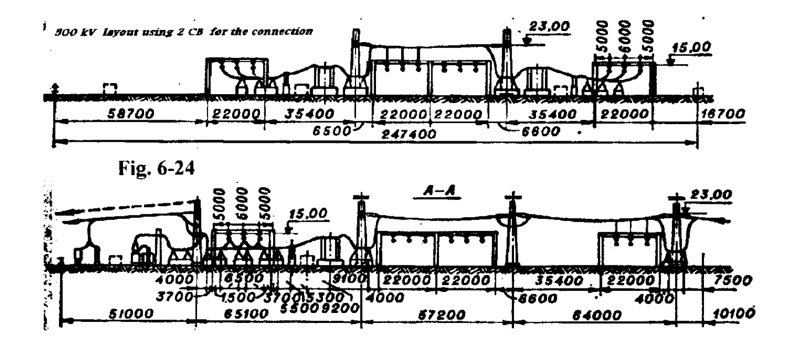



Fig. 6-24

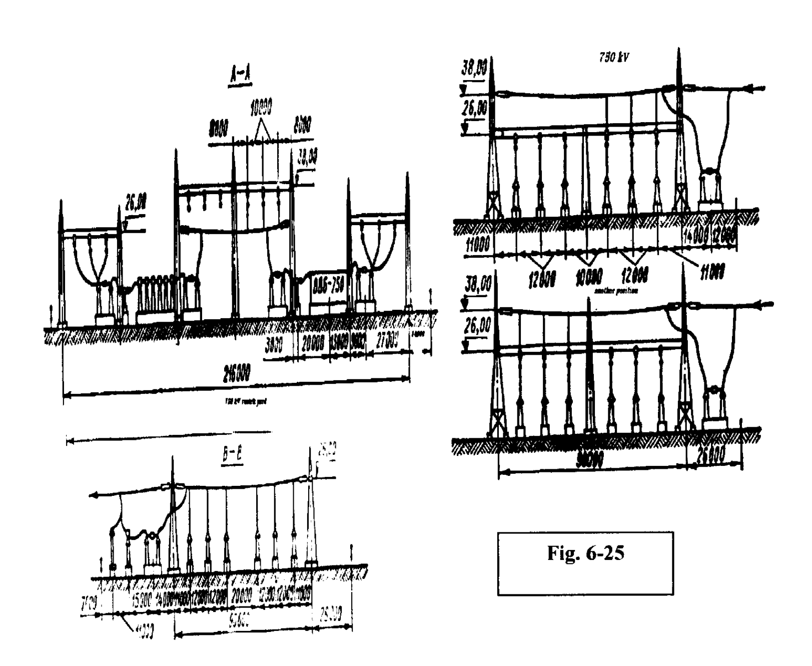



Fig. 6-25

## III- Triple Breakers Diagrams

**For the 500 kV above diagrams it is needed to raise the reliability due to the heavy transmitted power through the cells. Fig. 6-26 presents the use of three circuit breakers for the connection between a transformer cell and a transmission line cell. This clarifies the benefits from such schemes (Fig. 6-27). The single line diagram explains the connection well.**

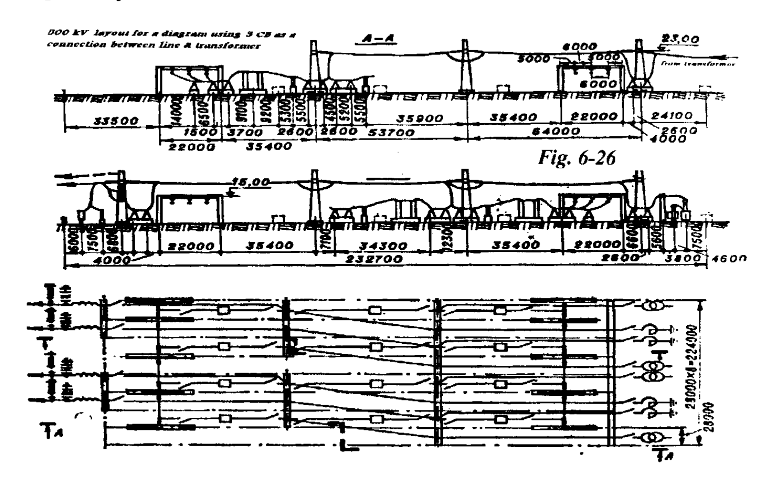



*Fig. 6-26*

## IV- Four Circuit Breakers

**The use of three circuit breaker is a useful tendency so that the increase of one circuit breaker with them leads to a more reliable than the triple implementation. This design is presented in Fig. 6-27 for the 500 kV level.**

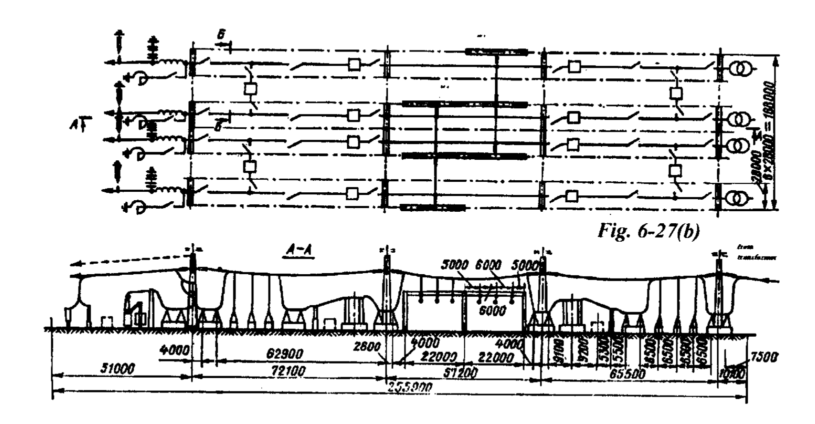


*Fig. 6-27(b)*

## V- Transfer Bus Dependence

**The transfer bus or the standby (Reserve bus) can be implemented typically as in Fig. 6-28 for the 330 kV as a single line diagram while for 220 kV it may be shown in Fig 6-29.**

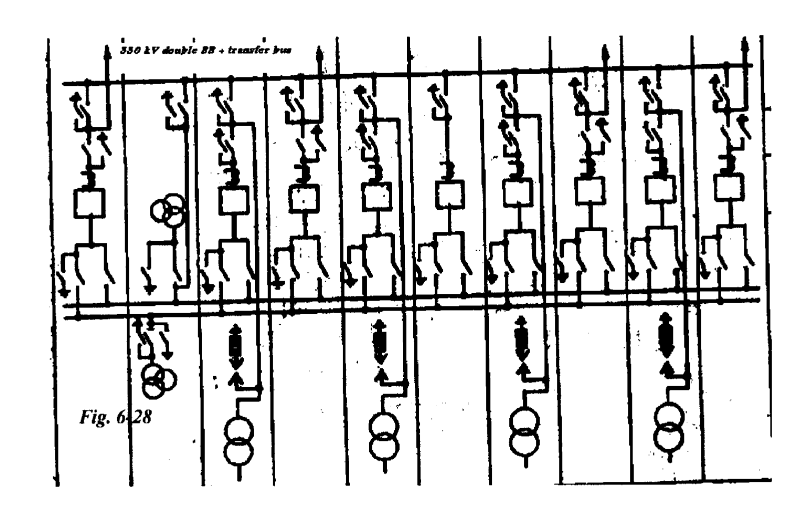



*Fig. 6-28*

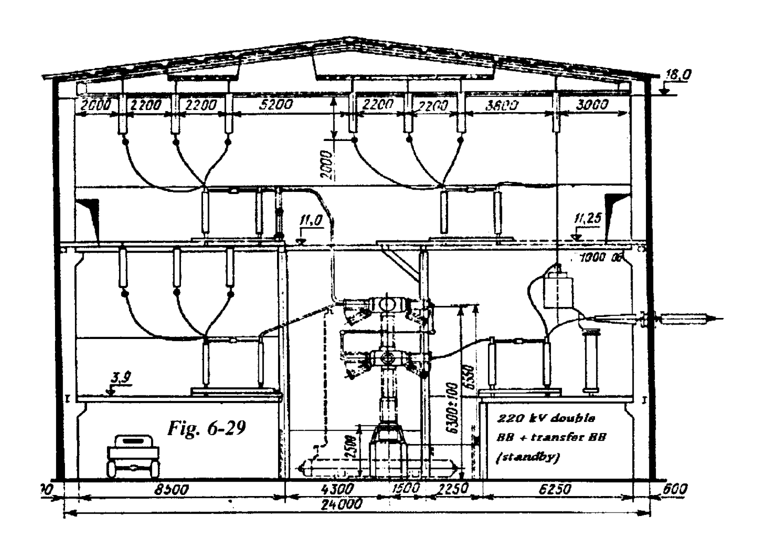



*Fig. 6-29*

# 6-4: Auxiliaries

Auxiliaries in power stations and substations include many and many titles such fire fighting, water pumping, cooling systems, compressed air piping and many others. We would study the related direct items to the design of a station for examples as it is followed in the next lines.

## I- Control Room

This room is the vital point in a station as a result to the possibility for operation inside the control room. This control room controls the processes of switching and the determination of the places of faults or abnormal operation inside. The critical cases may be indicated also inside as well as the treatment for a faulty condition occurred. It consists of a main panel or some panels as illustrated in Fig. 6 - 30 where Fig. 6 - 30(a) gives a simple sketch hand for one of the possible distributions of the panels inside the room. In the figure the sub-panels are given in the behind of the main panel. On the other hand, a typical picture for the control room main panel is given in Fig. 6 - 30(b). Each of them treats a certain cell in the site outdoor or indoor. On the other hand Fig. 6-30 (c ) and (d) present the shapes for the sub-main control panels.

*Fig. 6-30 (a) one possible layout for a control room*

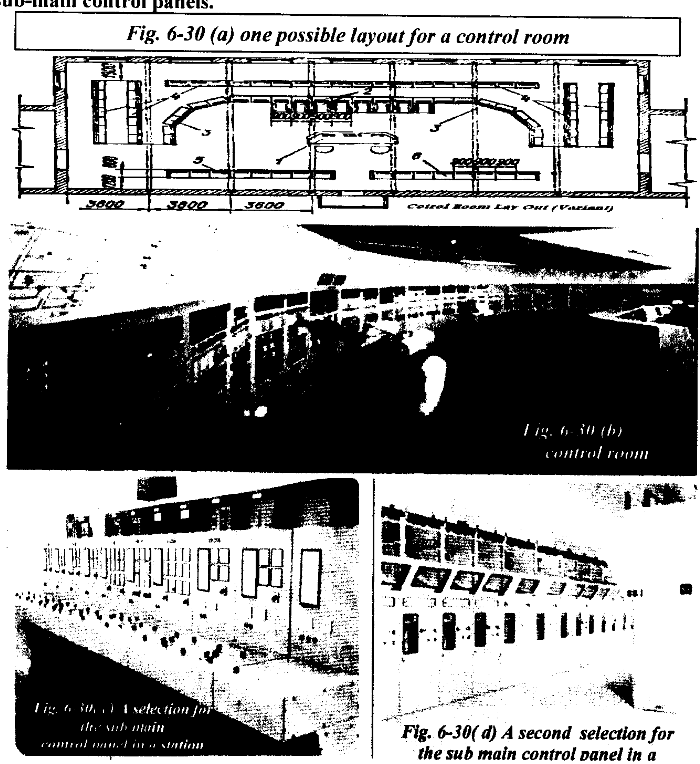



*Fig. 6-30 (b) control room*

*Fig. 6-30(c) A selection for the sub main control panel in a station*

*Fig. 6-30( d) A second selection for the sub main control panel in a*

## II- Secondary Wiring

**Secondary conductors are the elements of either the control circuits or the protective schemes. They are the heart of the secondary circuits for a station such that any fault in the wire may cause a damage for the station or any part of it. Consequentially, the method of wiring must be done according to the international specifications. This means that the wiring system should be implemented through underground tunnels (See Fig. 6-31).**

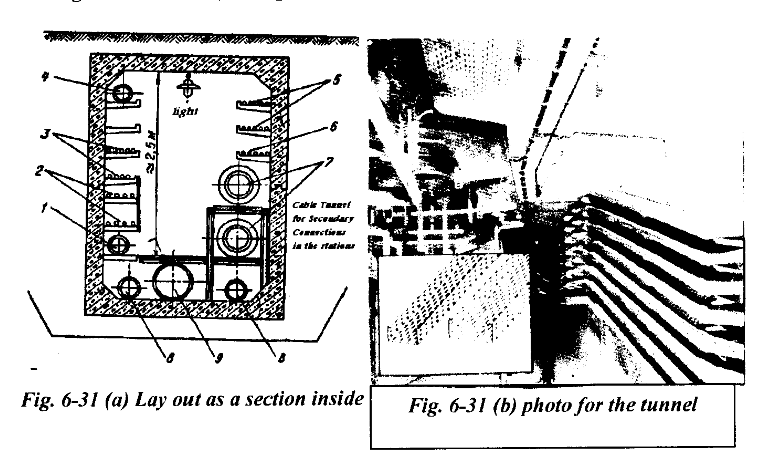



*Fig. 6-31 (a) Lay out as a section inside*

*Fig. 6-31 (b) photo for the tunnel*

**The supporting arms takes a conductor as specified with quantity and diameter. Each type of circuits must be avoided from interference with others as illustrated in the figure. The light weight conductors may be above as well as a lighting lamps should be installed in order to cover the processes of wiring as the maintenance.**

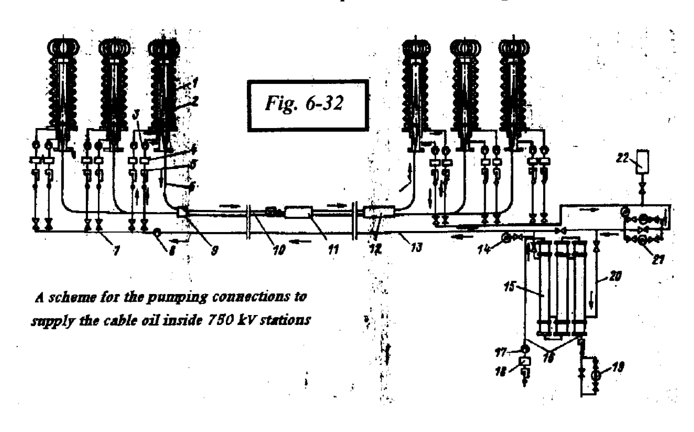


*Fig. 6-32*

*A scheme for the pumping connections to supply the cable oil inside 750 kV stations*

## III- Pumping Stations

One of the most rarely cases is shown in Fig. 6-32 where the oil pumping system is given. This figure illustrates the importance of insulation inside bushing although it is a small part. The pressure of the cable oil inside the bushing is defined so that a minimum value for the pressure should be signaled. The system is shown in the figure well. Also, such system can be done for the piping of compressed air to supply the air blast circuit breakers.

## IV- Reactor Implementation

The long length UHV transmission lines must terminates at a shunt reactor to overcome the Ferranti Effect and Fig. 6-33 shows the shunt reactor application in the single line diagram at a 500 kV station with the view of high frequency wave trap which is used as a modem for the telephone carrier system.

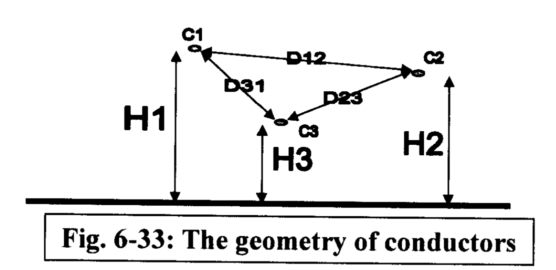



Fig. 6-33: The geometry of conductors

# 6-5: Economic operation

Economic operation is a very important tendency for any power system to return a self profit on the capital. This is fixed by regulatory paddies and the importance of conservation of fuel place pressure on power companies (As the present situation in Egypt) in order to achieve maximum possible efficiency. This maximum efficiency will minimize the cost of energy in KWH received to a consumer and the cost to the company of delivering that KWH in the face of constantly rising prices for running cost such as fuel, labor, supplies, maintenance and others.

Operational economics involving power generation and delivery can be divided as economic dispatch and the energy loss. At a specified load dispatch center determines the power output of each plant which minimizes the overall cost of fuel consumed to serve the system load as a coordination of the production costs at all power. This can be done through the control of power flow to be minimum. This gives the meaning of importance of the good design of the single line diagram as well as the layout as discussed above.

The optimal power flow can be viewed as a sequence of conventional Newton Raphson power flow method, in which certain controllable parameters are automatically adjusted to that satisfy the network constraints while minimizing a specified objective function . It depends on the economic distribution of the output of a plant between the generators or units within it. This, also, can be applied to economic scheduling of the plant outputs for a given loading of the system without

**consideration of transmission losses . These losses are a function of the outputs of the various plants so that the output of each of the plants of a system is scheduled in order to achieve the minimum cost of power delivered to the load terminal.**
**Coordinated control of the power plant out puts is a necessary to ensure generation to load balance so that the system frequency will remain as close as possible to the nominal operating value , usually 50or 60 Hz .**
**Accordingly, the problem of automatic generation control (AGC) is developed from the steady state viewpoint due to the daily load variation so that the utility has to decide on the basis of economics which generators to either start up or shut down. The computational procedure for making such decisions is called unit commitment.**

## I- Distribution of load between units within a plant

**An early attempt at economic dispatch called for supplying power from only the most efficient plant at light loads. As load increased, power would be supplied by the most efficient plant until the point of maximum efficiency of the plant was reached then, for further increase in load the next most efficient plant would start to feed power the system and third plant would not be called upon until the point of maximum efficiency of the second plant was reached (even with transmission losses neglected). This method fails to minimize cost. The economic distribution of a load between the various generating units inside a station (consisting the costs of a turbine and generator operations, and the steam supply) should be realized. The variable operating costs of a unit must be expressed in terms of the power output where the fuel cost is the principal factor in fossil – fuel plants. Also, the cost of nuclear fuel can be expressed as a function of output.**
**We base our discussion on the economics of fuel cost with the realization that other costs which are a function of power output can be included in the expression for fuel cost .a typical input -output curve which is a plot of fuel input for a fossil- fuel plant in British thermal units (BTU/H) versus power output of the unit in MW.**
**The ordinates of this relationship are converted to dollars per hour by multiplying the fuel input by the cost of fuel in dollars per million BTU. If a line is drawn through the origin to any point on the input –output curve, the slope can be expressed in millions of BTU/H divided by the output in MW, or the ratio of fuel input (BTU) to energy output in MWH. This ratio is called the heat rate and its reciprocal is the fuel efficiency. The lower heat rates imply higher fuel efficiency where maximum fuel efficiency occurs at that point where the slope of the line from the origin to a point on the curve is a minimum, that is, at the point where the line is tangent to the curve.**
**The fuel requirement for a given output is easily converted into dollars per MWH. The criterion for distribution of a load between any two units inside the station is based on whether increasing the load on one unit as the load is decreased on the other unit by the same amount results in an increase or decrease in total cost. This incremental fuel cost is determined by the slopes of the input – output curves of the two units. If we express the ordinates of the input – output curve in $/H and let:**

$F_i$=input to unit number (i), ($/H)
$P_{gi}$ =output of unit number (i), (MW) (6-1)

The incremental fuel cost of the unit in dollars per megawatt hour is $dF_i/dp_{gi}$, whereas the average fuel cost in the same units is $F_i/P_{gi}$. If the input –output curve of unit (i) is quadratic, then

$$F_i = (a_i/2) \times P_{gi}^2 + b_i \times P_{gi} + C_i \qquad \$/H \qquad (6\text{-}2)$$

And the unit has incremental fuel cost denoted by $\lambda$ (i), which is defined by

$$\lambda_i = dF_i/dP_{gi} = a_i \times P_{gi} + b_i \quad \$/MWH \qquad (6\text{-}3)$$

where $a_i$, $b_i$ and $c_i$ are constants. The approximate incremental fuel cost at any particular out put is the additional cost in \$/H to increase the output by one MW. Actually, incremental cost is determined by measuring the slope of the input – output curve and multiplying by cost per BTU in the proper units. A typical plot of incremental fuel cost versus power output can be technically approximated to a straight line without any loss in the accuracy. In analytical works, the curve is usually approximated by one or two straight lines. The equation of this line is defined by

$$\lambda_i = dF_i/dP_{gi} = 0.0126P_{gi} + 8.9 \qquad (6\text{-}4)$$

For more accuracy, two straight lines (not one) may be drawn to represent this curve in this upper and lower range.

All the above lines give the background to understand the principle of economic dispatch which guides distribution of load among the units within one or more plants of the system. For instance, suppose that the total output of particular plant is supplied by two units and that the division of load between these units is such that the incremental fuel cost of one is higher than that of the other. Then, suppose that some of the load is transferred from the unit with the high incremental cost to the unit with the lower incremental cost. Reducing the load in the unit with the higher incremental cost will result in a greater reduction of cost than the increase in cost for adding the same amount of load to the unit with the lower incremental cost. The transfer of load from one to the other can be continued with a reduction in total fuel cost unit the incremental fuel costs of the to units are equal. The same reasoning can be extended to a plant with more than two units. This economic view can be reflected on the layout design of a station in order to simplify the process of adding fuels to the boilers.

Thus, for economical division of load between units within a plant, the criterion is that all units must operate at the same incremental fuel cost. When the incremental fuel cost of each of the units in a plant is nearly linear with respect to power output over a range of operation under consideration, equations that represent incremental fuel cost as linear functions of power output will simplify the computations.

An economic dispatch schedule for assigning loads to each unit in a plant can be prepared in steps :

1- Assuming various values of total plant output.

2- Calculating the corresponding incremental fuel cost ($\lambda$) of the plant.

3- Substituting the value of ($\lambda$) for ( $\lambda_i$) in the equation for the incremental fuel cost of each unit to calculate its output.

Thus, a curve for ($\lambda$) versus plant load establishes the value of ($\lambda$) at which each unit should operate for a given total plant load. For a plant with two units operating under economic load distribution the($\lambda$) of the plant equals ($\lambda_i$) of each plant, and so

$$\lambda = df_1/dP(g_1) = a1 \times P(g_1) + b_1$$
$$\lambda = df_2/dp(g_2) = a_2 \times P(g_2) + b_2 \qquad (6\text{-}5)$$

solving for $P(g_1)$ and $P(g_2)$, we get

$$P(g_1) = ( \lambda - b_1) / a_1$$
$$P(g_2) = ( \lambda - b_2) / a_2 \qquad (6\text{-}6)$$

Then, the required total power of the load may be estimated in the form

$$P(load) = P(g_1)+P(g_2) \qquad (6\text{-}7)$$

The savings effected by economic distribution of load rather than some arbitrary distribution can be found by integrating the expression for incremental fuel cost and by comparing (increase/ decrease) case of cost for the units as load is shifted from the most economical allocation. This will facilitate the processes of calculations and thus, the processes of switching of the cells of a certain units can be ready in advance.

## II- unit commitment:

Because the total load of the power system varies throughout the day and reaches a different peak value from one day to another ( The daily load curve), the electric utility has to decide in advance which generator to start up and when to connect them to the network-and the sequence in which the operating units should be shut down and for how long. The computational procedure for making such decisions is called *unit commitment*, and a unit when scheduled for connection to the system is said to be *committed*. Therefore, the commitment of fossil-fuel units which have different production costs because of their dissimilar efficiencies, designs, and fuel types should be considered. Although there are many other factors of practical significance which determine when units are scheduled (ON/OFF) to satisfy the operating needs of the system, economics of operation is of major importance. Unlike on line economic dispatch which economically distributes the actual system load as it arises to the various units already on line, unit commitment plans for the

best set of units to be available to supply the predicted or forecast load of the system over a future time period.
To develop the concept of unit commitment, we consider the problem of scheduling fossil-fired thermal units in which the aggregate costs(such as start-up costs, operating fuel costs, and shut –down costs )are to be minimized over a daily load cycle. The underlying principles are more easily explained if we disregard transmission loss in the system. Without losses , the transmission network is equivalent to a single plant bus to which all generators and all loads are connected, and the total plant output $P_{gt}$ , then equals the total system load P(D). The 24-h a day can divided into discrete *interval* or *stage* and the predicted load of the system will be considered constant over each interval.
The unit commitment procedure then search for the most economic *feasible combination* of generated units to serve the forecast load of a system at each stage of the load cycle. The power system with k generating units (no two identical) must have at least one unit on-line to supply the system load which is never zero over the daily load cycle. If each unit can be considered either *on*(denoted by 1)or *off* (denoted by 0), there are $2^{K-1}$ candidate combinations to be examined in each stage of the study period. For example, if k = 4, the 15 theoretically possible combinations for each interval are combinations (See Table 6-2).

**Table 6-2: The theoretically possible combinations**

| Unit | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{15}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| 3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| 4 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

In this table $X_i$ denotes the combination *I* of the four units. Of course, all combinations are not feasible because of the constraints imposed by the load level and other practical operating requirements of the station according to the single line diagram and its layout or of the system itself. For example, a combination of units of total capability less than 1400 MW can not serve a load of 1400 MW or greater, any such combination is *infeasible* and can be disregarded over any time interval in which that level of load occurs. The mathematical formulation of the unit commitment problem may be taken the assumption that the combination $X_i$ of interval k is $X_i$ (k) and so $X_j(k+1)$ represents combination $X_j$ of interval (k+1). If k equals 1 and i equals 9 in the four – unit example above, the combination $X_9(1)$ means that only units 1and 2 are on – line during the first interval.
The production cost incurred in supplying power over any interval of the daily load cycle depends on which combination of units is on –line during that interval. For a given combination $X_j$ the minimum production cost $P_j$ equals the sum of the economic dispatch costs of the individual units. Accordingly, we designate that $P_j(k)$ will be equal to the minimum production cost of combination $X_j(k)$ and then $P_j$ (k+1) would be the minimum production cost of combination $X_j$ (k+1). Also *a transition cost*, which is the cost associated with changing from one combination of power – producing units to another combination should be considered. Usually, a fixed cost is assigned to shut down a unit, which has been operating on the system, since *shut-down* cost is generally independent of the length of time it has been running. However, in practical situations the *start- up* cost of a unit depends on

**how long the unit has been shut down from previous operation (Refer to the lay out of the cell concerned).**

**This is to be expected since the boiler temperature of the unit and fuel required. The fuel is needed to restore operating temperature depending on the duration of cooling. Assuming a fixed start-up cost for each unit and referring the reader to other practical consideration and then, transition cost $T_{ij}(k)$ associated with changing from one combination of operating units $X_i$ (k) to another $X_i$ (k+1) will have fixed start-up and shut down components denoted (from interval k to interval k+1). If each unit could be started up or shut down without incurring any transition cost, then from the economic viewpoint the problem of scheduling units to operate in any one hour would become disjoint from and totally unrelated to the scheduling problem in any other hour of the load cycle.**

**On the other hand, suppose that it costs $ 1500 to shut down a unit and $ 3000 for each unit start up then, to change from combination $X_2(k)$ to combination $X_3$ (k+1) to the above four unit example, the transition cost $T_{2,3}(k)$ becomes ($1500+$3000) =$4500 because unit 3 is to shut down and unit 4 is to start up at the beginning of interval (k+1). Furthermore, the status of units in interval (k+1) affects the cost of transition to interval (k+2),and so on .**

**Therefore, transition cost links the scheduling decision of any one interval to the scheduling. Decisions of all the other intervals of the load cycle. Accordingly, the problem of minimizing costs at one stage is tied to the combinations of units chosen for all the other stages, and we say that unit commitment is a *multistage* or *dynamic* cost- minimization problem. The dynamic nature of unit the commitment complicates its solution. Suppose that 10 units are available for scheduling within any one-hour interval, which is not unlikely in practice. Then, theoretically a total of $2^{10-1}$=1023 combinations can be listed. If it were possible to link each prospective combination of any hour to each prospective combination of the next hour of the day, the total number of candidate combinations becomes $(1023)^{24} = 1.726 \times 10^{72}$, which is enormously large and unrealistic to handle. Fortunately, however, the multistage decision process of the unit commitment problem can be dimensionally reduced by practical constraints of system operations and by a search procedure based on the following.**

**The daily schedule has N discrete time interval or stages, the durations of which are not necessarily equal. Stage 1 precedes stage 2, and so on to the final stage N. A decision must be made for each stage K regarding which particular combination of units to operate during that stage. This is the stage K sub-problem. In order to solve the problem for the N decisions, N sub-problems should be solved sequentially in such a way (called the *principle of optimality*) that the combined best decisions for the N sub-problems yield the best overall solution for the original problem. This strategy greatly reduces the amount of computation to solve the original unit commitment problem, then the cost may be expressed as**

$$F_{ij}(k) = P_i(k) + T_{ij}(k) \qquad (6\text{-}8)$$

**Which is the combined transition and production cost incurred by combination $X_i$ during interval K plus the transition cost to combination $X_j$ of the next interval. For ease of explanation it is assumed that the system load levels at the beginning and of the day are the same. Consequently, it is reasonable to expect that the state of the system is the same at the beginning and at the end of the day. Therefore, at**

K=N the transition cost $T_{ij}$ (N) becomes zero where the cost $F_{ij}$ (k) is tied by $T_{ij}$ (k) to the decision of the next stage (k+1). In order to know the *best policy* or set of decisions (in the sense of minimum cost ) over the first (N-1) stages of the daily load cycle, it is assumed that the best combination of the units for each of the first(N-1) intervals is chosen. If this combination $X_i$ is the best combination for stage (N-1), then, by searching among all the feasible combinations $X_j$ of the final stage N, then minimum cumulative cost of the final two stage starting with combination $X_i$ (N-1) and ending with combinations $X_j(N)$ may be formulated as

$$F_i (N-1) = \min \{P_i (N-1) + T_{ij} (N-1) + F_j(N)\} \{X_j(N)\} \qquad (6\text{-}9)$$

where the cumulative cost $F_j(N)$ of stage N equals the production cost $P_j$ (N) since there is no further transition cost involved. This means that the search for the minimum-cost decision is made over all feasible combination $X_j$ at stage N. Consequentially, we do not yet know which combination is $X_{i*}$ (N-1). For each possible starting combination $X_i$ (N-1), it is straight forward to solve for the best stage-N decision. This will store the corresponding minimum-cost results in a table for later retrieval when the best combination $X_i$ (N-1) has been identified.
Similarly, starting with the combination Xi(N-2) at interval (N-2), the minimum cumulative cost of *final three* stages of the study period is given by

$$F_i (N-2) = \min \{ P_i(N-2) + T_{ij} (N-2) + F_i(N-1)\}\{ X_j(N-1)\} \qquad (6\text{-}10)$$

where the search is now made among the feasible combinations $X_j$ of stage (N-1). Continuing the above logic, the recursive formula may be

$$F_i(k)=\min\{P_i(k) +T_{ij}(k)+F_j(K+1)\}\{X_i(K+1)\} \qquad (6\text{-}11)$$

For the minimum cumulative cost at stage K, where K ranges from 1 to N. According to the reasons stated earlier, it is required to reach the state being the same at the beginning and at the end of the day when K equals N in the last equation. When K equals 1, the combination $X_i$ (1) is the known initial condition input to the unit commitment problem. The combinations corresponding to subscripts i* and j change roles from one stage to the next; the combination $X_{i*}(k)$, which initiates one search among the feasible combinations $X_j$ (K+1), becomes one of the feasible combinations $X_j(k)$ which enter into all searches of stage (K-1).
This brief section is a good manner to help us in the subject of design of each generating cell in the layout as well as the importance of minimizing the loss across the conductors and all components in the cell. Thus the design of the single line diagram of a station would be a best one with the minimum loss and high reliable. Also, the study of the load curve appears to be a basic item in the given design.

# 6-6 : A PROFILE FOR SWITCHING TRANSIENTS

**This section needs a high mathematics that it is related to the switching transients on the basis of statistics and so, the different terms or symbols will be used are listed here in Table 6- 3.**

**Table 6-3: List of symbols**

| Symbol | meaning | symbol | meaning |
|---|---|---|---|
| [Z] | Impedance matrix | $R_c$ | Conductor resistance |
| [R] | Resistance matrix | $K$ | Total Number of points inside the time length |
| $x$ | Distance on the line measured from the sending end | A , B | Elements of the transformation matrix ( A= 1.2 , B= 1.8) |
| $N_t$ | Number of points of transients inside the time length | $\lambda_1$ , $\lambda_2$ and $\lambda_3$ | Roots of the characteristic equation for the propagation coefficients variable |
| $R_g$ | Ground resistance | $Z_{1,2}$ | Characteristic impedance |
| $L_s$ | Self inductance of a line | $Z_c$ | Surge impedance |
| $L_m$ | Mutual inductance of the line | $V(x)$, $I(x)$ | Voltage and Current at a point x |
| $C_s$ | Self capacitance of a line | $V(l)$, $I(l)$ | Voltage and current at the receiving end |
| $C_m$ | Mutual capacitance of a line | $\gamma$ , $\gamma_1$ and $\gamma_2$ | Propagation coefficients of the line |
| $\omega$ | Angular frequency | [X] | Inductive impedance matrix |
| *TN* | *Transient Number* | ($\alpha$) ,($\beta$), (0) | The three wave mode coordinates |
| [ T ] | Transformation matrix | $E$ , $L_{supply}$ | Voltage and current at the receiving end |
| $V_o$ | Average over-voltage | $\sigma$ | Standard deviation |
| $L$ | Line length | $T_o$ | Time interval duration |
| DTR | Distribution to transmission ratio | $\Sigma( Z_l )_D$ | Sum of the impedance of lines in the distribution system |
| | | $\Sigma( Z_l )_T$ | Sum of the impedance of lines in the transmission system |
| $TN_G$ | General transient number | $(N_t)_D$ | transient number for the distribution system |
| GR | General ratio | $(N_t)_T$ | transient number for the transmission system |

**Shunt capacitors are installed in large distribution systems and so, many critical nodes may be appeared]. The transient processes is a power network may lead to a damage for the operation either partially or completely in spite of it is related to the operation system itself. Otherwise, the switching transients may be internal or external and consequently, the study of such item must be significant to bring the system to the safe and suitable zone. Also, the transient phenomena can be occurred either for a long time length such as electromechanical type or for a short time as the electromagnetic switching processes. This subject takes the action with both transmission and distribution systems so that it may be investigated more and more in future. The impedance Z of a symmetrical line as a function of its parameters (conductor resistance $R_c$ and ground $R_g$ as well as self inductance L and mutual M may be formulated as given by:**

$$[Z] = [R] + j\,[X] = \begin{bmatrix} R_c+R_g & R_g & R_g \\ R_g & R_c+R_g & R_g \\ R_c & R_g & R_c+R_g \end{bmatrix} + j\omega \begin{bmatrix} L & M & M \\ M & L & M \\ L & M & M \end{bmatrix} \quad (6\text{-}12)$$

## I - MATHEMATICAL ANALYSISS

**There are some different approaches tried to regulate the parameters of a power system generally. Others went to transmission lines or even to change the concept of transmission but the final practical solution requires more effort. Also, there are new types of lines such as flexible AC transmission systems FACTS. The switching transients depends to a great extend on the parameters of the system where the ground return effect plays an important role. The earth will be considered as a homogenous for simplicity and so, the Carson concept would be applied. Otherwise, the capacitance is taken as a constant without any ground effect while the frequency dependent parameters are introduced. The self capacitance will be $C_s$ and the mutual will be $C_m$. Hence, this paper studies both systems transmission (500, 330, 220, 110 kV) and distribution (35, 10, 6 kV) as sample for any network in order to conclude the statistical performance for a system under the transient conditions. Hence, the random five values for the switching angle are applied to present the general case of switching transients. The overall geometry of phases on standard towers, as shown in Fig. 6-33, is listed in Table 6-4.**

**It is required to illustrate the objective aim of the study where certain national power system cannot be identical to the other. Then, the determination of a general performance for all networks through the investigation of any one may take us away from the actual condition in the site. However, the transient characteristics depend on mainly the parameters of a system where their values can be evaluated through the geometry of phases. This means that the geometry allocation of phases will reflect the overall behavior in the domain of electromagnetic transients. Therefore, the classes of distribution and transmission can be taken as the gate to solve such problem and consequently its generalization may be implemented. This projects the idea of the presented work according to the evaluation of the boundaries for the profile of switching transients in power system. The investigation may be tailored into two steps. The first will be for each system (Distribution or transmission) while the second deals with the statistical variation in length or voltage or even in the percentage content of a system relative to the other inside the network. After that, the general profile can be computed for different values of content ration (Distribution to transmission ratio). Otherwise, the data cannot be based on the population readings so that the statistical sampling processes must be inserted. The main equations of voltage and current at a point x of a line are given in a matrix form:**

$$-d/dx\,[V(x)] = [Z]\,[I(x)]$$
$$-d/dx\,[I(x)] = [Y]\,[V(x)] \quad (6\text{-}13)$$

**Also, the deduced Voltage at a point x with the help of Sylvester theorem may be found as:**

$$V(x)= 1/3\{ch\ \gamma_1(l-x)\ [M_1]+ch\ \gamma_2(l-x)[M_2]\})\ [v(l)]+1/3\{\ Z_1\ sh\ \gamma_2\ (l-x)\ [M_2]\ +Z_2\ sh\ \gamma_1\ (l-x)\ [M_1]\})\ [I(l)] \quad (6\text{-}14)$$

**Where**

$$[M_1]=\begin{bmatrix}1&1&1\\1&1&1\\1&1&1\end{bmatrix},\ [M_2]=\begin{bmatrix}2&-1&-1\\-1&2&-1\\-1&-1&2\end{bmatrix},\ Z_1^2=\frac{R+p(l-M)}{p(C-C_m)},\quad Z_2^2=\frac{R+3R+p(L+2M)}{p(C+2C_m)}$$

**Otherwise, the current can be derived as:**

$$[I(x)]=\{\ sh\ \gamma_2\ (l-x)\ [\ Z_c]^{-1}\ [v(l)]+ch\ \gamma_1\ (l-x)\ \ [I(l)] \quad (6\text{-}15)$$

**The replacement of the matrix of propagation coefficient by a multi term equation according to the rule of *Sylvester* will simplify the derived formula for the propagation coefficient $\gamma$.**

$$[\gamma]\ =\ 1/3\ \lambda_1\ [M_1]\ +1/3\ \lambda_2\ [M_2] \quad (6\text{-}16)$$

**where**

$$\lambda_1^2=\gamma_1+2\ \gamma_2 \qquad \& \qquad \lambda_2^2=\lambda_3^2=\gamma_1-\gamma_2$$

**Then, the formula of the propagation coefficient appears to be in the form:**

$$e^{[\gamma]\ x}\ =1/3\ e^{\lambda_1 x}\ [M_1]\ +\ 1/3\ e^{\lambda_2 x}\ [M_2] \quad (6\text{-}17)$$

## II - MODAL COORDINATES { ($\alpha$) ,($\beta$), (0) }

**This result will be more complicated for the non-transposed lines in the *Laplacian* domain and so the final formula can be solved in the wave mode coordinates. On the other hand, the distribution power networks plays an important role in the processes of operation and many papers were analyzed this system as in. The modal technique gives the simplicity for the solution of such problems in the complex plane so that the main parameters of the deduced equation (6-17) may be applied in each of the modes of the analysis.**

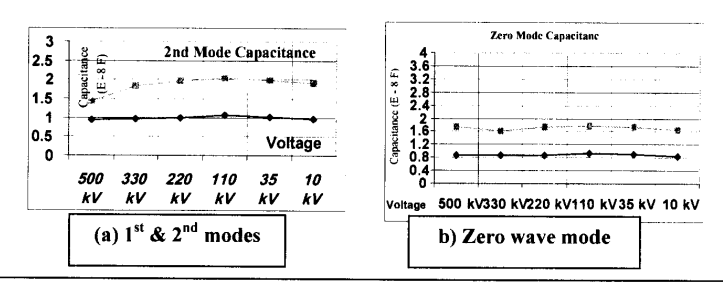



**Fig 6-34: The computed values for the capacitance in the wave modes of different lines.**

**The modes are individual channels without any mutual relationship between them and they defined as { (α) ,(β), (0) }. Therefore, the parameters of the system must be evaluated. So, a capacitance is calculated for different phase geometry shapes in modal coordinates as shown in Fig. 6-34. Two limits (upper and lower) are indicated where both channels { 1st (α) & 2nd (β) } have a higher value than that for the zero wave mode(0). It is increasing with voltage level in the two modes but it is a constant in the zero mode. The propagation coefficient is varied in these coordinates a shown in Fig. 6-35 where per unit system is considered.**

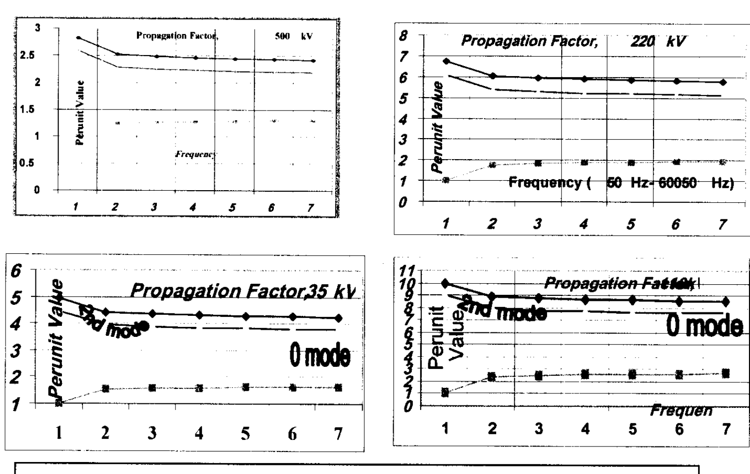



**Fig 6-35: The value variation of propagation coefficient for the studied lines.**

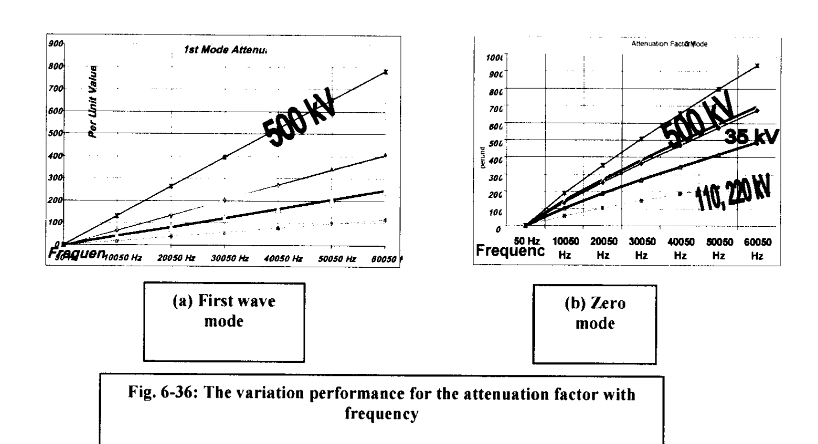
The frequency presence inside the processes of transients may reach 60 kHz due to the HF loads and interference with electromagnetic fields. The 50 Hz t zero mode position is taken ass the reference (unity value) and then its value is illustrated for studied voltage levels. The coefficient is increasing with frequency in Zero mode coordinates while it is decreased in other channels. The maximum ratio of this coefficient is appeared for 110 kV, where the 35 kV distribution lines approaches the case of 500 kV. This approves that the distribution network is subjected normally to heavy transients relative to its level where its value my exceed that for EHV levels. This coefficient can be shown mathematically in each channel from equation (6-17) to obey the formula 6-18:

$$e^{[\gamma] x}= e^{\gamma_\alpha x}\{(\gamma_\beta- \gamma)(\gamma_0 -\gamma)\}/\{(\gamma_\beta - \gamma_\alpha)(\gamma_0 - \gamma_\alpha)\} + e^{\gamma_\beta x}\{(\gamma_\alpha -\gamma)(\gamma_0-\gamma)\}/\{(\gamma_\alpha- \gamma_\beta)(\gamma_0- \gamma_\beta)\} + e^{\gamma_0 x}\{(\gamma_\alpha-\gamma)(\gamma_\beta - \gamma)\}/\{(\gamma_\alpha- \gamma_0)(\gamma_\beta - \gamma_0)\}=$$

$$= e^{\gamma_\alpha x}\begin{bmatrix}1&0&0\\0&0&0\\0&0&0\end{bmatrix} + e^{\gamma_\beta x}\begin{bmatrix}0&0&0\\0&1&0\\0&0&0\end{bmatrix} + e^{\gamma_0 x}\begin{bmatrix}0&0&0\\0&0&0\\0&0&1\end{bmatrix} \quad (6\text{-}18)$$

On the other hand, the attenuation factor plays great role in the limitation of the over-voltages since it is representing the effective part of the propagation process. The characteristic is shown in Fig. 6-36 where the maximum ratio is corresponding to the higher voltage class. However, the wood tower standards give a lower attenuation so that its value for 35 kV towers may exceed that for the 110 and 220 such towers. The derived equations will be more complicated for the non-transposed lines in the *Laplacian* domain (p) and so the initial formula can be solved in modal coordinates. Also, the distribution networks play an important role in the operation conditions s analyzed before. Many methods are known for the transient calculations and the wave mode propagation method will be selected because it is valid for either transposed or non-transposed lines. It depends on the transformation matrix [T] , which takes the form

$$[T] = \begin{bmatrix}1&1&1\\0&-B&A\\-1&1&1\end{bmatrix} \quad (6\text{-}19)$$




(a) First wave mode

(b) Zero mode

**Fig. 6-36: The variation performance for the attenuation factor with frequency**

**If the basic differential equations (6-13) are specified to the modal coordinates, new - deduced expressions become individually:**

$$-d/dx\,[V(x)_{\alpha,\beta,0}] = [Z]\,[I(x)_{\alpha,\beta,0}]$$
$$d/dx\,[I(x)_{\alpha,\beta,0}] = [Y]\,[V(x)_{\alpha,\beta,0}] \qquad (6\text{-}20)$$

**Then, voltage and current at point x in modal coordinates will be in the form of**

$$[V(x,p)]_{\alpha,\beta,0} = [ch\,\gamma(l-x)]_{\alpha,\beta,0}\,[V(l,p)]_{\alpha,\beta,0} + [sh\,\gamma(l-x)]_{\alpha,\beta,0}\,[Z_c]_{\alpha,\beta,0}\,[I(l,p)]_{\alpha,\beta,0}$$

$$[I(x,p)]_{\alpha,\beta,0} = [sh\,\gamma(l-x)]_{\alpha,\beta,0}\,[Z_c]^{-1}_{\alpha,\beta,0}\,[V(l,p)]_{\alpha,\beta,0} + [ch\,\gamma(l-x)]_{\alpha,\beta,0}\,[I(l,p)]_{\alpha,\beta,0} \qquad (6\text{-}21)$$

**These equations depend on the transformation of the phase system into another one, which is known as the wave mode system. This means that the wave modal concept has three isolated modes without any mutual effect between them as this can be reached through the mathematical theorem of *Eigen values* and *Eigen vectors*. It should be noted that the transformation matrix of Eq. 6-19 is the *Eigen vectors* for the system. A special program is used for the calculations of parameters in wave modes or the transients and modified to measure the statistical values as presented here. The application of parameters in modal axes is based on the matrix equation:**

$$[E] = [T]\,[Z_c \,\mathrm{ch}\, \gamma l / \mathrm{sh}\, \gamma l]\,[T]^{-1}[I(0)] \qquad (6\text{-}22)$$

**For easy computation these equations must be referred to the voltage source at the sending end instead of the voltage at receiving end. Then, a simplified formula for voltage and current can be expressed as**

$$\begin{aligned}
&[V(x,p)]_{\alpha,\beta,0} = [\mathrm{ch}\,\gamma x]_{\alpha,\beta,0}\,[V(0,p)]_{\alpha,\beta,0} + \\
&[\mathrm{sh}\,\gamma x]_{\alpha,\beta,0}\,[Z_c]_{\alpha,\beta,0}\,[I(0,p)]_{\alpha,\beta,0} \\
&[I(x,p)]_{\alpha,\beta,0} = [\mathrm{sh}\,\gamma x]_{\alpha,\beta,0}\,[Z_c]^{-1}_{\alpha,\beta,0}\,[V(0,p)]_{\alpha,\beta,0} + \\
&[\mathrm{ch}\,\gamma x]_{\alpha,\beta,0}\,[I(0,p)]_{\alpha,\beta,0} \qquad (6\text{-}23)
\end{aligned}$$

**It is important to find the wave velocity in the proposed wave modes as shown in Fig. 6-37. It would be indicated that the voltage source differs from that at the sending end of line according to the relation**

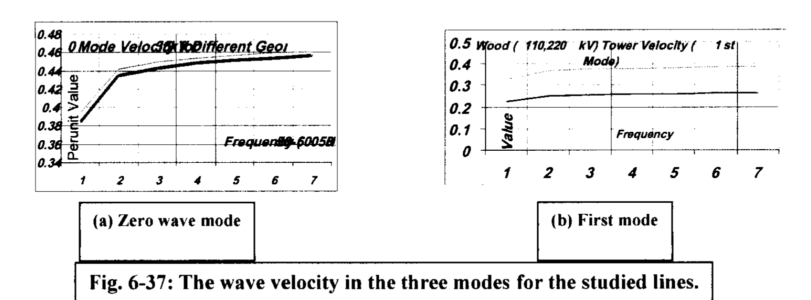
$$[V(0,p)]_{\alpha,\beta,0} = [E(p)]_{\alpha,\beta,0\,0} - p\,[L_{supply}] \qquad (6\text{-}24)$$

**Consequently, the voltage may be formulated through the transformation matrix**

$$[V(x,p)]_{\alpha,\beta,0} = \{[\mathrm{ch}\,\gamma(l-x)/\mathit{sh}\,\gamma l]_{\alpha,\beta,0}\,[E(p)]\}/\{B\,[Z_c]_\alpha\,\{[\mathrm{ch}\,\gamma(l-x)/\mathit{sh}\,\gamma l]_\alpha + A\,[Z_c]_\beta\,\{[\mathrm{ch}\,\gamma(l-x)/\mathit{sh}\,\gamma l]_\beta\} \qquad (6\text{-}25)$$

**Therefore, voltages in phase coordinates can be determined numerically according to the convolution theorem as given in**

$$\begin{aligned}
V_a(x,p) &= A\,V_\alpha + B\,V_\beta + (A+B)\,V_0 \\
V_b(x,p) &= A\,B\,(V_\beta - V_\alpha) \\
V_c(x,p) &= A\,V_\alpha + B\,V_\beta - (A+B)\,V_0 \qquad (6\text{-}26)
\end{aligned}$$




**(a) Zero wave mode**

**(b) First mode**

**Fig. 6-37: The wave velocity in the three modes for the studied lines.**

Similarly, the equations of currents in phase coordinates can be found, so the number of points of transients along the lines for both distribution and transmission systems in a percentage base ( K=140, T=0.23 ms) can be derived as shown in Fig. 6-38.

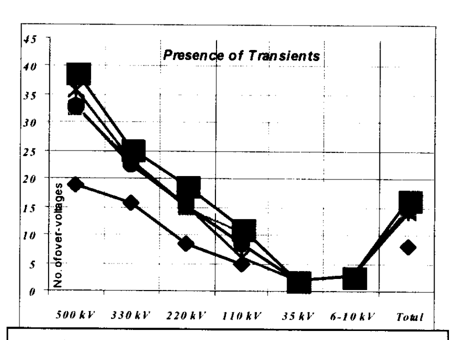



*Fig. 6-38 : Number of points of transients along the lines for both distribution and transmission systems in a percentage base (*

## III - STTISTICAL SWITCHING TRANSIENTS

Moreover, the variation of time domain length has been examined as given in Fig. 6-39. An interval duration of 0.21 ms was considered for 100, 200 and 400 points of calculation. Larger interval (T=0.23ms) was taken for 140 and 300 ms. The computed verge over-voltage V is illustrated in Fig. 6-39 (a) but the standard deviation is shown in Fig. 6-39 (b). The dependence of average value on time domain is deduced s time is changed from 21 to 64 ms (Fig. 6-40).

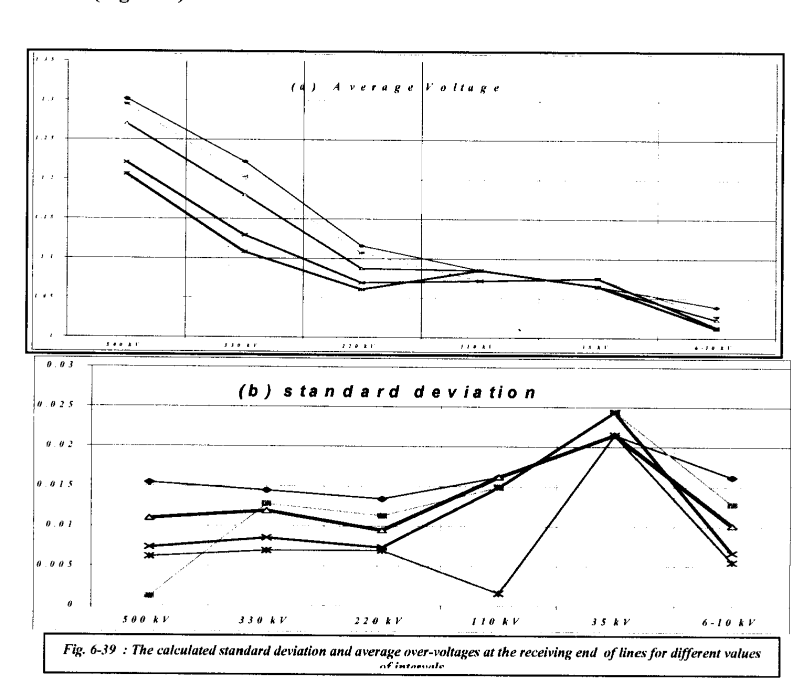
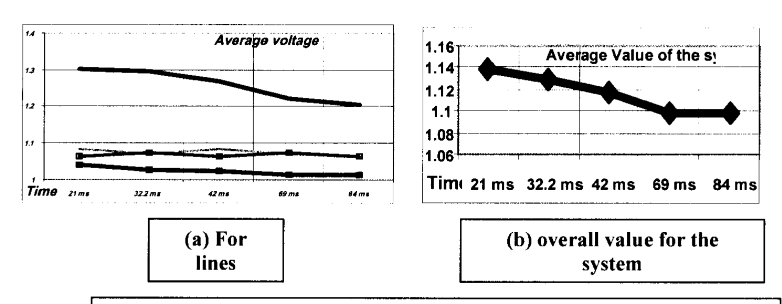



*Fig. 6-39 : The calculated standard deviation and average over-voltages at the receiving end of lines for different values of intervals*




(a) For lines

(b) overall value for the system

**Fig. 6-40: Number of over-voltages at the receiving end of lines for different values of intervals (%)**

**In the above results, the combination of changing of either interval or number of points in the domain length clarified the effect of steady state presence in long time term for 500 kV. The low voltage distribution system (6-10 kV) gives gradually decrease with time domain length while it is approximately constant for 35 kV. Also, the overall average voltage for studied lines is decreased due to the presence of steady state period inside the process of calculations. Otherwise, the effect of interval only for a constant value for the points of computations (300) is considered and the results are listed in Table 6-6 for both verge voltage and standard deviation.**

## 1- TRNSIENT NUMBER

**The transient presence in a system during the switching processes my be important to measure the level of its action on the insulation level. The paper presents a number for such simulations. It represents the percentage presence of over-voltages inside the time length considered and so, it can be expressed mathematically in the form:**

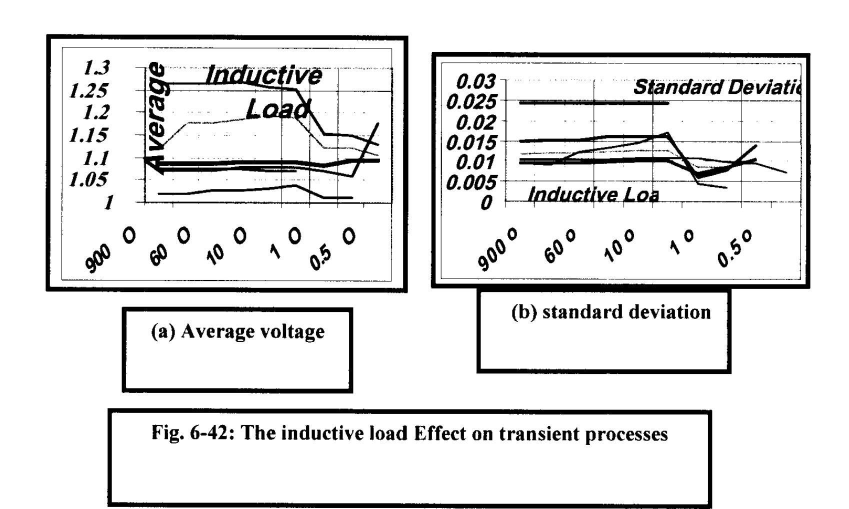
$$TN = N_t / K \tag{6-27}$$

**The presence of transients for each case is drawn in Fig. 6-41, a, but the overall presence will be shown in Fig. 6-41, b. It is seen that the transients are always decreased with voltage level except some readings of 220 kV relative to 110 kV due to the closed dimensions of towers for both levels (Table 6-4). This voltage is decreased with respect to the interval, which reflects the total time domain length. This confirms the deduced results above of Fig. 6-40. Also, the same conclusion can be derived from Fig. 6-41, b. The calculated average value ($V_0$) and standard deviation ($\sigma$ ) for transient voltages along the lines for both distribution and transmission systems ( K=140, $T_0$=0.23 ms) is listed in Table 6-5.**

## 2- COMPENSATION EFFECT

**The reactive part of elements connected to a power system takes a part in the switching processes as soon as voltage control in the distribution system needs shunt capacitor on loads. This may be transferred (directly or non-directly) to the**

low voltage line in the case of heavy loads. This capacitor may be appeared also in EHV and UHV transmission systems. Whatever, the load type has been tested where both inductive and capacitive loads are introduced at the receiving end of the switched lines. Results are shown in Fig. 6-42 for the inductive condition for a time length of 200 points with 023 ms interval. It shows a normal characteristic while the heavy transients appears with the second condition (capacitance).




(a) Average voltage

(b) standard deviation

Fig. 6-42: The inductive load Effect on transient processes

It would be required to indicate that the capacitive effect reached faster in the distribution system. It began at 10 Ohms for 6 kV with a per unit value of 37.14 while this value became 16.82 for 35 kV lines. The other lines still in the normal but the resonance condition may come later. It varied with potential level as the final will be the highest one.

The resonance characteristics are shown through curves in Fig. 6-43 although the standard deviation became very large. This means that the value of actual maximum voltage is high. The curves for 220 and 330 kV are not illustrated. Fig. 6-44 shows well that the presence of transient inside the time length is higher with nominal potential and it is very high for the capacitive condition.

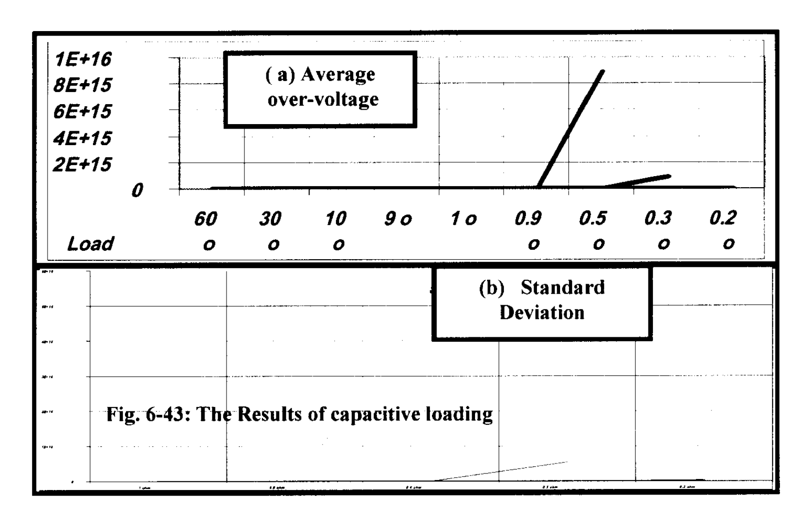



Fig. 6-43: The Results of capacitive loading

The average voltage distribution at the receiving end of the lines studied but for all possible lengths is computed as given in Fig. 6-45. It proves that the switching transients in EHV and HV lines will have a great role in the design of such lines and it decayed for the distribution system. Also, the effect of line length shows an average value for each length in spite of the different potentials (Fig. 6-45, b). The derived standard deviation is drawn in Fig. 6-46 with different lengths of lines when the transient number is presented in Fig. 6-47. These curves indicated the same conclusion defined above.

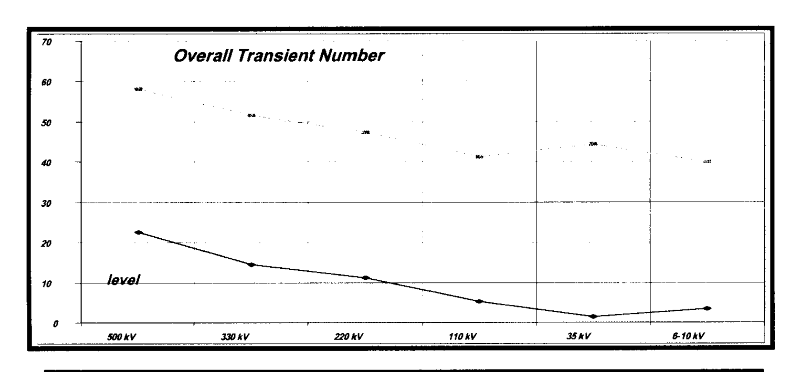



Fig. 6-44: The overall transient number in both cases of inductance and capacitance.

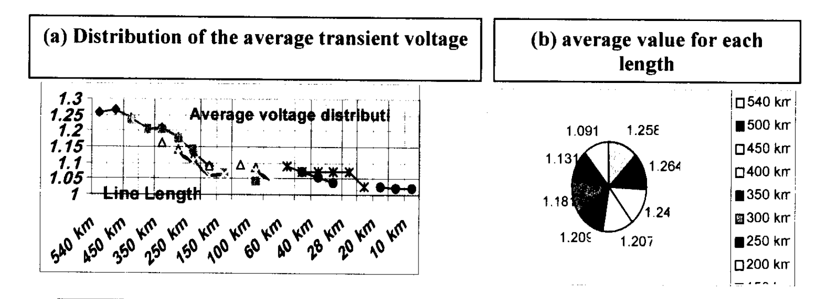



**Fig. 6-45: The calculated average value for different line lengths at K=200**

**Nevertheless, the shunt compensation by the installation of rector at receiving end would be the best solution for long lines t EHV and UHV systems due to the reduced statistical transient presence (as the value of TN). Whatever, shunt capacitors on feeders of thee distribution networks represent critical condition with bulk reactive powers so that a great interest would be needed with sudden change of load according to the performance of load curves at such points.**

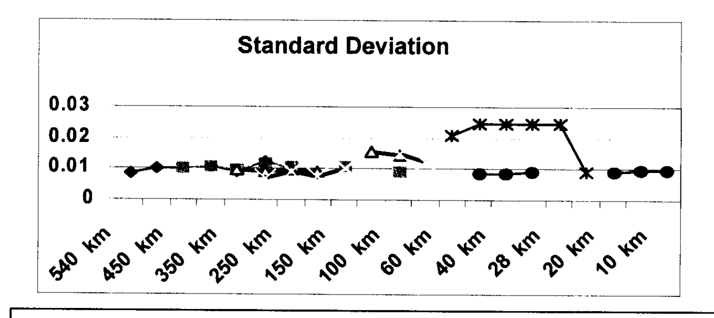



**Fig. 6-46: The calculated average value for different line lengths at K=200**

## IV . STATISTICAL PROFILE

**The process of profiling for a group of data may be expressed mathematically either through a deterministic or by a stochastic concept. The deterministic style is a mathematical model, which means the actual specified all data are included in the system while the stochastic concept gives an overall view for the system through either all data or some random values. Although this last concept may introduce an error according to the statistical principles, a good result expressing a problem can be easy achieved. This will be more difficult with the internal transients. Therefore, the above analysis can be used to get a general profile for the processes of switching transients in a certain specified network.**

Any network contains different numbers of distribution and transmission systems. There is a specified ratio of these systems at a certain moment but this ratio will be varied with each extension, which must be normally happened, continuously, at least in the distribution system. So, the ratio between both systems inside the network will be actually a dynamic ratio. Therefore, a general profile for such specified network at a certain moment can solve the problem of generalization of the view for this network. Thus, the distribution to transmission ratio (DTR) my be defined by

$$(DTR) = \Sigma(Z_l)_D \quad / \ \Sigma(Z_l)_T \qquad (6\text{-}28)$$

Consequentially, line impedance can be computed according to the specific resistance and inductance multiplied by the length and then, the summation of impedance for either transmission or distribution would be evaluated. After that, a defined profile for a network should be deduced for at a certain network at a specified time but a general profile for this network may be evaluated at all values of (DTR).
On the other hand, a general ratio (GR) may be proposed as:

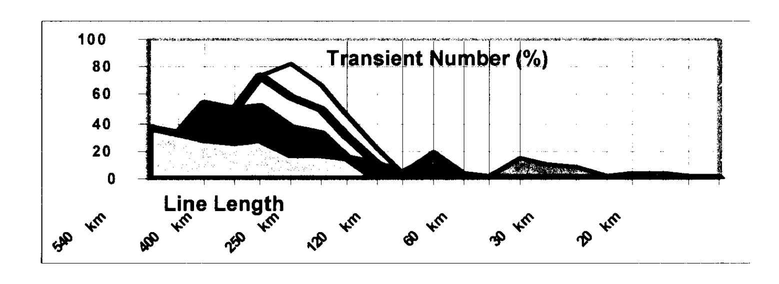



Fig. 6-47: The derived transient number for different line lengths at K=200

$$(GR) = DTR \, / \, (1+ DTR) \qquad (6\text{-}29)$$

This will be useful to find the general profile for a network through the general transient number by:

$$TN_G = (GR)[\ (N_t)_D - (N_t)_T\ ]/\ K\ +\ (N_t)_T\ /\ K \qquad (6\text{-}30)$$

This general transient number may be evaluated for system specified, but it may be important to find its change due to the growing in the electric systems as a whole. So, a basic configuration for a power system is suggested as listed in Table 6-7 where both transmission and distribution systems re indicated according to the self parameter for each voltage level. Then, different cases with the variation of

such power system are considered on the bases of normal growth in the developing counties. The impedance is referred to the 11 kV impedance as calculated statistically above while the percentage content for either the transmission (500, 220, 110 kV) or the distribution (35, 11, 6 kV) level with the determined transient number. Therefore, the constant configuration for the transmission system is considered (basic case), where the variation is applied to the distribution level.

The general transient number is computed for each case as shown in Fig 6-48. Also, the change in the transmission system is given (cases 4 and 5). It is shown that the transient content in a network will be increased with the growing in the distribution network. This may give more increase with the great extension in the lower level of voltage so that a corresponding extension will be needed as proved for the case 4, where the 110 kV increased. It should be indicated that this extension balance cannot be achieved t the highest UHV scale (case 5).

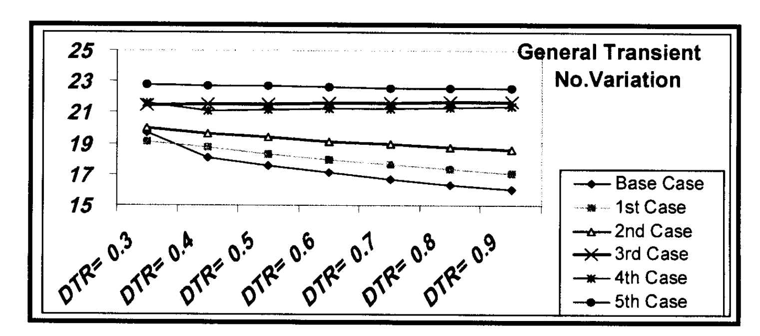



Fig. 6-48: The deduced profile for the proposed cases of transmission and distribution systems

Thus, the proposed technique will be useful for the planning and design of power systems in order to decrease the transient level inside a network. This may be clarified with the rate of rise of the transient content as given in Fig. 6-49 for the studied cases referring to the basic one. The rate of rise is increased with 6 kV (35 %) although it reaches 40 % for the UHV extension. This proves that the proposed concept for the general transient number must be considered for any extension to avoid the heavy presence of transients in a power system. Finally, the proposed simplified concept for the evaluation of transients in both transmission and distribution systems through the transformation into the so called the wave mode coordinates. Also, it is valid for both transposed and non-transposed phases. This value would be an importan6t factor for the selection of the circuit breaker type and capacity in the design procedure.
The use of bulk capacitors in the single line diagram for the designed station can be treated as the distribution power network according to the presented results for the transient presence in a percentage style. Also, with the limits of resonance phenomena may be derived simply. The overall transient number for the power stations or network in a statistical base has been realized so that the UHV and EHV still have the heavier transient presence. The statistical profile is a good tool

for the planning and design of electric stations or power systems specially with the quick developing networks. This case may be appeared in the developing countries where the great density of population will be presented.

**Table 6-4: The dimensions (in meters) for the considered towers in the research**

| Type | Tower | kV | H1 | H2 | H3 | D12 | D23 | D31 |
|---|---|---|---|---|---|---|---|---|
| Outdoor | Metal | 500 | 20–19 | 20–19 | 20–19 | 11-13 | 11-13 | 22-26 |
| | | 330 | 16-30 | 16-23 | 16-23 | 8.5-9.4 | 8.-8.6 | 16-7.5 |
| | | 220 | 18.5-30 | 14-24 | 14-18 | 6.8-7.1 | 6-6.86 | 6.8-13 |
| | | 110 | 15.5-18 | 12.5-15 | 12.5-12 | 4.24-3.27 | 5.5-3.27 | 4.24-6 |
| | | 35 | 12-17.5 | 9-14.5 | 9-11.5 | 3-3.08 | 3-3.06 | 4.24-6 |
| | | 6-10 | 9-8.9 | 9-7.6 | 9-7.6 | 1.5 | 1.5 | 3-1.5 |
| Outdoor | Wood | 220 | 12 | 12 | 12 | 5 | 5 | 10 |
| | | 110 | 9 | 9 | 9 | 4 | 4 | 8 |
| | | 35 | 11 | 11 | 11 | 3 | 3 | 6 |
| | | 6-10 | 9.5 | 8.75 | 8 | 1.5 | 1.5 | 1.5 |
| Indoor | Metal | 220 | 5.3 | 3.5 | 1.7 | 1.8 | 1.8 | 3.6 |
| | | 150 | 3.5 | 2.3 | 1.1 | 1.2 | 1.2 | 2.4 |
| | | 110 | 2.3 | 1.5 | .7 | .8 | .8 | 1.6 |
| | | 35 | 0.93 | 0.61 | .29 | .32 | .32 | .64 |
| | | 20 | 0.58 | .38 | .18 | .2 | .2 | .4 |
| | | 10 | 0.38 | .25 | .12 | .13 | .13 | .26 |
| | | 6 | 0.29 | .19 | .09 | .1 | .1 | .2 |
| | | 3 | 0.205 | .135 | .065 | .07 | .07 | .14 |

**Table 6-5: The calculated average value ($V_0$) and standard deviation ($\sigma$) for transient voltages along the lines for both distribution and transmission systems ( K=140, $T_0$=0.23 ms)**

| Point | L | Sending End | | ¼ of Line | | ½ of line | | ¾ of line | | Receiving End | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kV | (km) | $V_0$ | $\sigma$ | $V_0$ | $\sigma$ | $V_0$ | $\sigma$ | $V_0$ | $\sigma$ | $V_0$ | $\sigma$ |
| 500 | 500 | 1.067 | .003966 | 1.211 | .008909 | 1.336 | .01245 | 1.359 | .01317 | 1.295 | .00117 |
| 330 | 300 | 1.072 | .006459 | 1.159 | .0102 | 1.221 | .01281 | 1.235 | .01352 | 1.203 | .01278 |
| 220 | 200 | 1.056 | .009299 | 1.091 | .009596 | 1.121 | .01058 | 1.136 | .01116 | 1.107 | .01125 |
| 110 | 100 | 1.05 | .01194 | 1.044 | .00861 | 1.054 | .01017 | 1.061 | .01054 | 1.072 | .01488 |
| 35 | 30 | | | 1.075 | .02439 | 1.075 | .02439 | 1.075 | .02439 | 1.075 | .02439 |
| 6-10 | 10 | | | 1.027 | .01281 | 1.027 | .01281 | 1.027 | .01281 | 1.027 | .01281 |

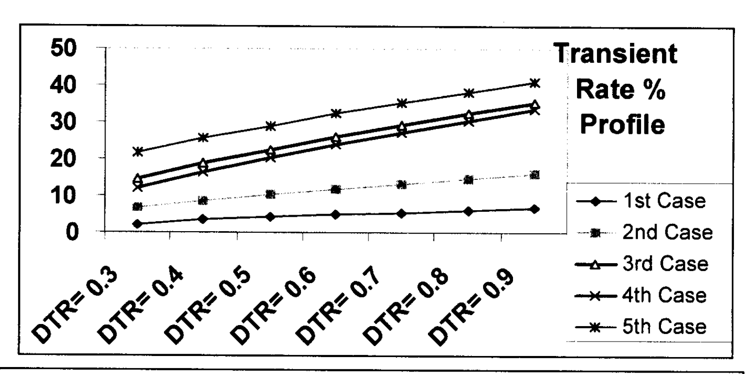



**Fig. 6-49 : The determined rate of rise of the transient content, referring to the base case for the proposed cases of transmission and distribution systems (%)**

**Table 6-6: The deduced average voltage level and standard deviation σ at the receiving end of lines for different duration of intervals at constant value of intervals ( K=300)**

| Voltage | Interval duration (ms) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | .23 | | .22 | | .21 | | .2 | | .12 | |
| kV | $V_o$ | σ | $V_o$ | σ | $V_o$ | σ | $V_o$ | σ | $V_o$ | σ |
| 500 | 1.221 | .007315 | 1.23 | .007373 | 1.23 | .007972 | 1.223 | .007648 | 1.291 | .008629 |
| 330 | 1.129 | .00846 | 1.135 | .00902 | 1.135 | .008887 | 1.156 | .009194 | 1.218 | .009699 |
| 220 | 1.069 | .00739 | 1.075 | .007491 | 1.075 | .008276 | 1.081 | .007405 | 1.123 | .00754 |
| 110 | 1.072 | .01488 | 1.085 | .0147 | 1.085 | .0162 | 1.047 | .008088 | 1.081 | .009005 |
| 35 | 1.075 | .02439 | 1.065 | .02348 | 1.065 | .02144 | | | | |
| 6-10 | 1.014 | .006732 | 1.015 | .007079 | 1.015 | .006912 | | | | |

**Table 6-7: The proposed value for the percentage content of transmission and distribution systems**

| Parameter | Z (p. u.) | Base Case | 1st Case | 2nd Case | 3rd Case | 4th Case | 5th Case |
|---|---|---|---|---|---|---|---|
| 500 kV | 13.2 | 30 | 30 | 30 | 30 | 30 | 40 |
| 220 kV | 7.2 | 50 | 50 | 50 | 50 | 40 | 40 |
| 110 kV | 4.8 | 20 | 20 | 20 | 20 | 30 | 20 |
| $(N_t)_T$ | | 21.3 | 21.3 | 21.3 | 21.3 | 20.7 | 23 |
| 35 kV | 2.8 | 30 | 10 | 10 | 10 | 10 | 10 |

| 11 kV | 1.0 | 50 | 60 | 50 | 40 | 40 | 40 |
|---|---|---|---|---|---|---|---|
| 6 kV | 1.36 | 20 | 30 | 40 | 60 | 60 | 60 |
| $(N_t)_D$ | | 10.15 | 12.4 | 15.55 | 22.1 | 22.1 | 22.1 |

**Table 6-8: The deduced profile for the proposed cases of transmission and distribution systems**

| DTR | Base Case | 1st Case | 2nd Case | 3rd Case | 4th Case | 5th Case |
|---|---|---|---|---|---|---|
| DTR=0.3 | 19.724 | 19.144 | 19.972 | 21.485 | 21.623 | 22.79 |
| DTR=0.4 | 18.111 | 18.755 | 19.656 | 21.529 | 21.1 | 22.74 |
| DTR=0.5 | 17.583 | 18.33 | 19.38 | 21.566 | 21.17 | 22.7 |
| DTR=0.6 | 17.119 | 17.962 | 19.144 | 21.6 | 21.225 | 22.66 |
| DTR=0.7 | 16.717 | 17.642 | 18.94 | 21.629 | 21.275 | 22.6 |
| DTR=0.8 | 16.349 | 17.348 | 18.747 | 21.655 | 21.322 | 22.6 |
| DTR=0.9 | 16.015 | 17.081 | 18.575 | 21.68 | 21.364 | 22.57 |

**Table 6-9: The determined rate of rise of the transient content, referring to the base case for the proposed cases of transmission and distribution systems (%)**

| DTR | 1st Case | 2nd Case | 3rd Case | 4th Case | 5th Case |
|---|---|---|---|---|---|
| DTR=0.3 | 2.24 | 6.664 | 14.746 | 12.28 | 21.72 |
| DTR=0.4 | 3.556 | 8.53 | 18.87 | 16.51 | 25.57 |
| DTR=0.5 | 4.25 | 10.24 | 22.655 | 20.381 | 29.1 |
| DTR=0.6 | 4.924 | 11.83 | 26.176 | 23.99 | 32.38 |
| DTR=0.7 | 5.533 | 13.28 | 29.382 | 27.27 | 35.37 |
| DTR=0.8 | 6.111 | 14.67 | 32.46 | 30.415 | 38.23 |
| DTR=0.9 | 6.656 | 15.982 | 35.368 | 33.397 | 40.95 |



# Chapter VII

# New Energy Technologies

**Researchers in the energy and earth sciences take also an atomic-level look at our world. For those in the energy sciences, the targets are the physical properties and chemical processes behind the production and consumption of energy. In the earth sciences, researchers are studying the environment above and below our planet's surface. Mention the term "energy research" and the image most likely to be conjured is that of massive power plants or sprawling factories. Although the new energy technology does investigate ways of improving the efficiency and reducing the pollution of such plants, its scientists are also conducting research into areas less dramatic but no less important. For example, consider the act of switching on a light. American taxpayers annually spend an estimated $30 billion in energy costs for electrical lighting--including residential, commercial, industrial and street lighting, plus lighting for miscellaneous purposes such as stadium events (according to the registered load curve practically). This accounts for about 25 percent of the electrical energy consumed in the U.S each year. Scientists believe that this consumption could be cut in half if existing lighting systems were to be replaced with new energy-efficient illumination. To this end, they have been working with industry to improve the illumination and energy-efficiency of fluorescent bulbs as a marketable replacement for energy-wasting incandescent bulbs. This past year, however, saw the unveiling of an even newer technology that has the potential to rewrite the future course of electrical lighting. Scientists call this promising new technology as *molecular emitter lamp* but it will probably come to be known to consumers as the "sulfur lamp".**

**Four times more energy efficient and 700 times brighter than a conventional incandescent bulb, the sulfur lamp also outperforms the best of the new fluorescent bulbs. The first lamp, produced in conjunction with Fusion Lighting Inc. of Rockville, Maryland, consisted of a glass globe the size of a golf ball that was filled with argon gas and a tiny amount of non-toxic sulfur, rather than the toxic mercury gas used in fluorescent tubes. Microwaves were used to electrically charge the argon gas which in turn heated the sulfur and made it glow, giving off a rich bright light that described to having a miniature sun in the room. A prototype version of the lamp is now on public display in Washington D.C. at both the U.S. Department of Energy's headquarters and at the Smithsonian Institution's National Air and Space Museum.**

**Equally important to national energy conservation efforts are energy-efficient windows. Each year, the amount of money required to offset the heat lost in the winter and gained in the summer through windows costs American taxpayers about $25 billion--a loss comparable, in terms of energy, to the amount of oil delivered through the Alaska pipeline. Scientists, through such projects as "super windows" and the new and improved "smart windows," have been transforming windows from an energy liability to an energy asset.**

**In addition to research on lights and windows, scientists also develop computer models that simulate all aspects of energy consumption inside buildings. Given that Americans spend more than 80-percent of their time indoors and that more than $200 billion of this country's yearly energy bill is spent on meeting indoor energy needs, the potential for savings is substantial. These past years, energy researchers released new most successful simulation programs. This is a tool to help engineers**

and architects reduce energy consumption in the buildings they design or retrofit. This will minimize the loss of loads besides the transmission loss as explained in the chapter 6. The new programs can calculate the hourly energy use and its costs of any type of commercial or residential building annually based on such information as the dimensions, construction materials, geographic location and orientation of the building, plus local weather data. If given the local utility rates, the program will even calculate the building's annual energy bill. The energy-efficiency of alternative building designs can be compared and optimized long before any concrete is poured.

Energy researchers have not ignored the larger problem of factory waste and pollution. The scientists who developed a cost-effective technology for clearing the air of sulfur dioxide pollution from power and chemical plants have now taken a big step toward clearing the water of future pollution from pulp and paper mills. They developed a chemical process called "POZONE" that cuts in half the cost of producing ozone. By putting ozone, which is a molecular form of oxygen that can serve as an environmentally benign bleach, on a cost-competitive footing with chlorine, the POZONE process will help paper manufacturers meet proposed new standards. This may raise a certain amount of load away from the station, generating the power. In the past, ozone-bleaching has been considered too costly because the production of ozone involved an expensive electricity-based process. POZONE produces ozone through the inexpensive chemical reaction of yellow phosphorus with oxygen. The potential for POZONE extends well beyond the pulp industry, because the technique can also be used to recycle carbon that has been used by a large number of different industries to adsorb toxic solvents. This contaminated carbon has traditionally been buried, which means it can pose a threat to groundwater.

In spite of removing buried toxic wastes that have been found to be contaminating groundwater has always been difficult, assessing the risk posed by these underground sites has proved troublesome. Artificial and natural pools tasks require the drilling of holes into soil that is of such poor quality (which is why it was chosen as a burial site for waste). It often crumbles and clogs up the hole. Conventional drilling mud used to stabilize commercial bore holes can't be used for fear of spreading contaminants even further. Earth scientists may have found a solution with the development of a drill that blasts super-cold nitrogen gas as it bores, creating frozen holes that won't collapse even in the most difficult of soils. In this technique, which is called "cryogenic drilling," nitrogen is injected down the drill's center pipe and exits through nozzles near the spinning drill bit. At 196 degrees-below-zero Celsius, the gas freezes difficult soils rich in sand, gravel or ash long enough for workers to insert stabilizing metal casings into the holes before the ground thaws. Thus, reflected subjects may vary in a wide range that can be said in the present chapter. These items could be the next type of energy generation although it may cost more and expensive today.

## 7-1: Solar Pond Technology

A typical solar pond has three regions (See Fig. 7-1). The top region is called the surface zone, or upper convective zone. The middle region is called the gradient zone, or non-conductive zone. The lower region is called the storage zone or lower convective zone. It may be the future power stations as the generated power must be connected to the network. The solar pond is one of the simplest devices for

**direct conversion of solar energy into thermal energy. Moreover, it is simultaneously a collector of solar radiation and a thermal storage device. the artificial solar pond prevents either vertical convection or surface evaporation and convection or both.**

**The lower zone (Fig. 7-1) is a homogeneous, concentrated salt solution that can be either convective or temperature stratified. The convective gradient zone constitutes a thermally insulating layer that contains a salinity gradient. This means that the water closer to the surface is always less concentrated than the water below it. The surface zone is a homogeneous layer of low-salinity brine or fresh water. If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone, because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it.**

**Because water is transparent to visible light but opaque to infrared radiation, the energy in the form of sunlight that reaches the lower zone and is absorbed there can escape only via conduction. The thermal conductivity of water is moderately low, and if the gradient zone has substantial thickness, heat escapes upward from the lower zone very slowly. This makes the solar pond both a thermal collector and a long-term storage device.**

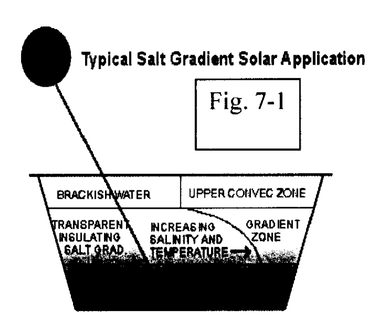


Fig. 7-1

## I- Non-convective ponds:

**Non convicting ponds prevent heat loss by inhibiting thermal buoyancy convection. In natural ponds isolation is converted into heat within the pond, but the warmed water from the bottom rises to the surface and most of the heat is lost to the atmosphere. Non-convective ponds employ a salt gradient to prevent the warmed water from rising to the surface where the salt concentration in such pond is highest near the bottom and lowest near the surface. As solar radiation enters the pond whatever is not absorbed in the water is absorbed on the dark bottom.**

### a) Salt Concentration

**Consequentially, the heat must be collected at the bottom and then, deeper waters warm up. However, the increased density created by the salt prevents this thermal buoyancy convection. Heat transfer to the pond surface primarily by conduction. Vertical convection takes place in the top layer due to the effects of wind and evaporation. This layer serves no useful purpose and is kept as thin as possible.**

The next layer, which may be approximately 1m thick, has a salt concentration that increases with depth; this layer is non-convective.

The bottom layer ,which is convective (constant slat concentration) .

The cost of salt for a solar pond represents a sizable fraction of the total initial investment. A suitable salt has several criteria:

1- It must be adequately soluble with a solubility that increases with temperature.

2- Its solution must be adequately transparent to the solar radiation.

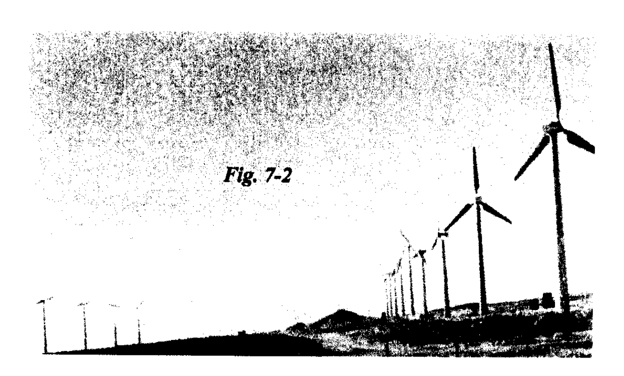
3- It must be environmentally safe.

### b) Solar pond applications

Solar pond are readily applicable for such low-temperature uses as residential or commercial heat. They can be used for either cooling systems or electric power generation. This indicates that the pool generation stations may come later as the bulk generating hydro power stations or nuclear stations.

## 7-2: Wind Stations

Wind Turbine System at the Campus Center for Appropriate Technology is simple as the mechanical mechanism in general may be the most important part while the fans or turbines can be taken as the general view as given in Fig. 7-2.


*Fig. 7-2*

In addition to solar power and a back-up generator, Humboldt State University's CCAT (Campus Center for Appropriate Technology), for example, uses a Whisper H500 wind turbine system to meet its energy needs. Also, a brief history about wind energy may be required for remember.

## I- History:

Wind-generated electricity is simply a new application for an old idea. According to the U.S. Dept. of Energy's (DOE) Wind Energy Program website, wind power has been used since earliest recorded history. There is evidence that wind energy was used to propel boats along the Nile River as early as 5000 B.C. Several centuries before Christ, simple windmills were used in China to pump water. In more modern times in the United States, windmills were erected as the West was developed during the late 19th century. Most windmills were used to pump water for farms and ranches. By 1900 small electric wind systems were developed to

**generate direct current, but most of these units fell out of favor when rural areas became attached to the national electricity grid during the 1930s. By 1910, wind turbine generators were producing electricity in many European countries.**
**Recently, wind power has become an appealing alternative to fossil-based fuels, especially in countries with scarce petroleum and ample wind. According to the Danish Wind Turbine Manufacturers Association, there were 1,129 MW of installed wind capacity spread out over 4784 turbines in Denmark in 1997.**
**This technology has a potential for further use in the U.S. (see http://www.eren.doe.gov/wind/we_map.html). This site contains a map of annual average wind speeds throughout the fifty states of USA. Areas with the highest average amount of wind (such as mountain ridges and coastal areas) would produce the most electricity. According to the DOE's web site, "North Dakota, alone, has enough energy from ... winds to supply 36% of the electricity of the lower 48 states". This may be a wind map for any required new design area such in Egypt now. Thus, the investment in the field of energy generation by wind can be easily proceed. It is important to put advantages and disadvantages of the wind power generation as follows.**

## II- Advantages of wind energy

**Zero emissions- CCAT's wind turbine does not produce any greenhouse gases or pollution, such as Carbon Dioxide, Nitric Oxides or Methane. As a result, CCAT has less overall environmental impact than if it were to rely on fossil fuels and nuclear power.**
**1- The space which wind farms occupy can still be used for agriculture, grazing, ranching or most other uses before the turbines were installed. Turbines can be mounted on top of buildings- imagine the Windy City's (Chicago's) skyline covered by hundreds of turbines (See Fig. 7-2).**
**2- Financially, turbines pay for themselves quicker than most other types of energy production. If one invests $10,000 in a family-size wind turbine system (tower, inverter, turbine, accessories, etc.), and the turbine produces $1000 of electricity savings per year, the system pays for itself in ten years.**
**3- Maintenance is minimal. According to World Power Technologies' owner manual, monthly maintenance consists of visual inspections of the mechanical condition of the turbine, inspecting the tower, and testing the brake. Annual maintenance consists of battery inspections and an up close inspection of the turbine.**
**It should be marked here that the wheeling fans have many different shapes as given in Fig. 7-3. They are either single or double or multi blade fan type.**

## III- Disadvantages of wind energy

**Disadvantages for the wind plant in a brief items can be treated as follows:**
**1- Avian (bird) mortality is being studied currently to determine if industrial wind turbine farms contribute to the demise of large birds of prey such as golden and bald eagles. Preliminary results indicate that avian mortality is specific to the site (if it's on a flyway), not the turbines in general.**
**2- Noise may also be a concern, especially with large turbine blades that are close to the ground.**

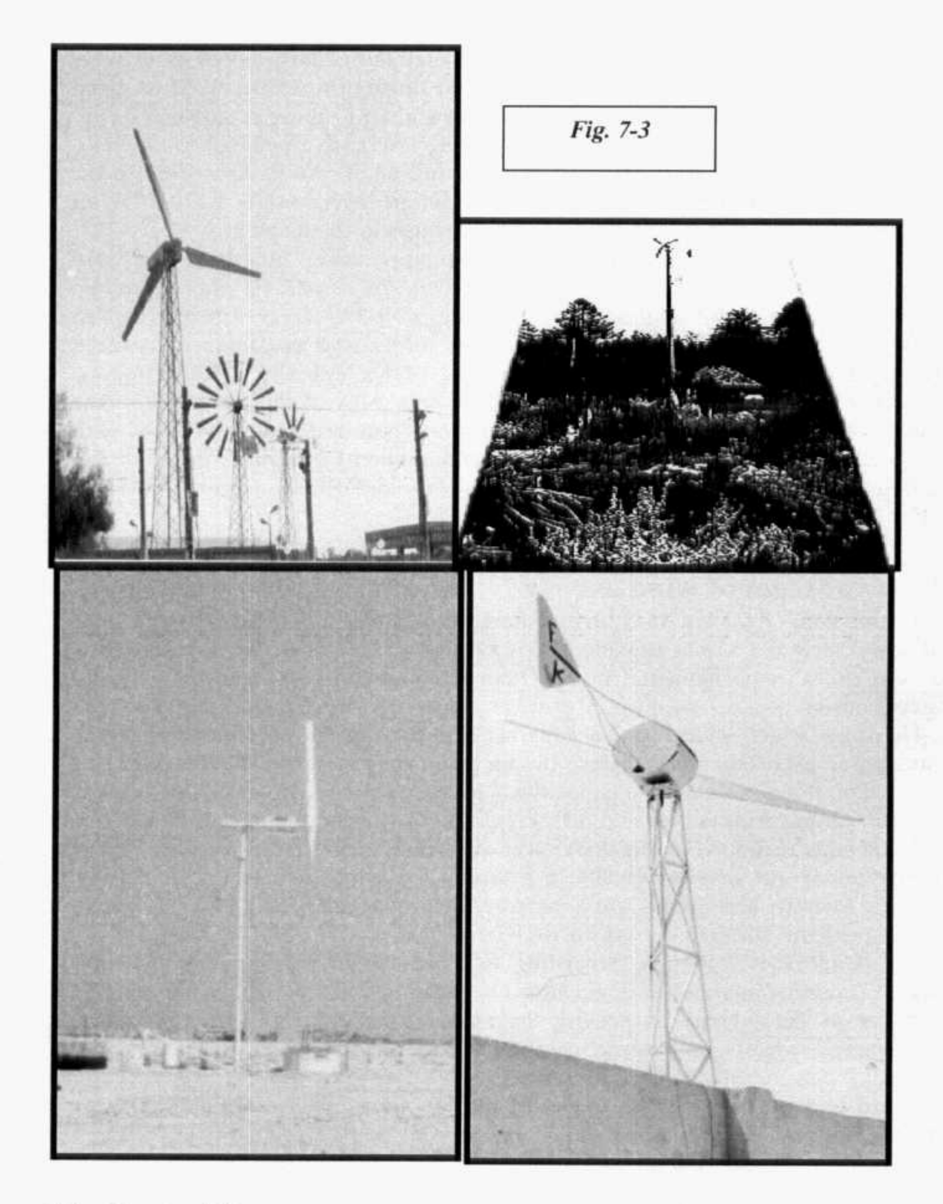


*Fig. 7-3*

## IV- Control Box

**The control box ( Fig. 7-4) performs the function of distributing the power produced by the wind turbine. In the upper left-hand corner of the box is a digital display. This displays the Volts per cell, Volts per battery, Amps per battery, Amps from the wind, Amps from Photovoltaic cells, or Amps Load, depending on where the adjacent switch is set. In the upper center is a guide to how fully charged the batteries are. The upper right hand corner of the box has a switch that sets the voltage at which the batteries are charged.**

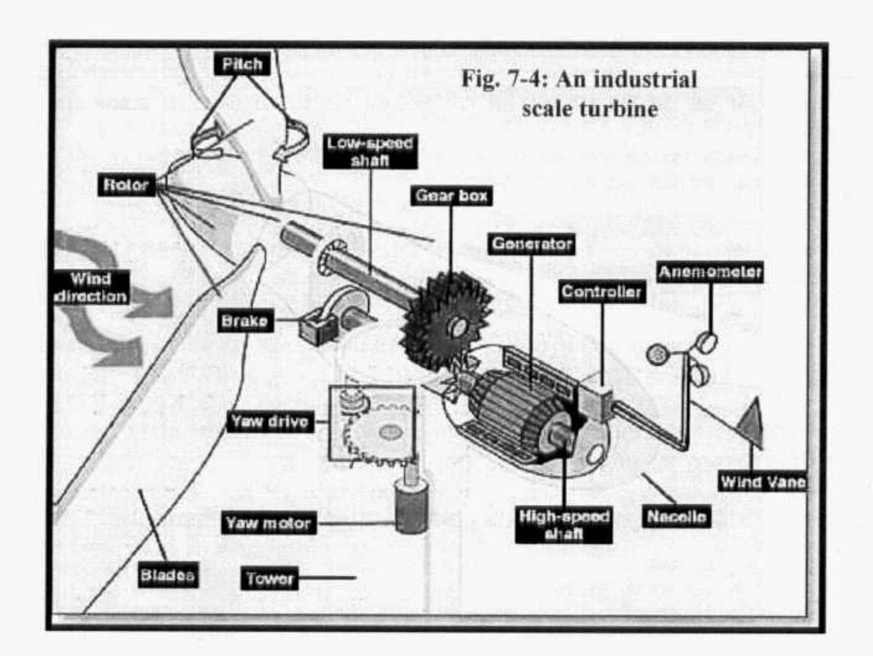


Fig. 7-4: An industrial scale turbine

**On the right hand side of the control box is a load that will dispose of excess electricity by heating a coil. The bottom right of the control box contains switches that will control whether the load for the house is on or not and whether solar power is on. There is an additional switch for braking the turbine in the lower center.**

## V- Kinetic energy of wind

**Aiming to present a brief but possibly integral design procedure for wind Mills (WM s) the main physical relations describing a WM operation will be presented. Wind is a moving air having a mass m ρ which depends on air pressure, temperature, air contents and pollution. Since it is a moving mass, it has an inherent kinetic energy Wρ which may be described as (Fig. 7-5):**

$$W\rho = 1/2\ m\rho\ v_o^2 \qquad (7\text{-}1)$$

**Where v is the speed in m/s of the moving mass in kg. so the obtained energy will be in kg m s i.e. Nm. joule or Watts.**

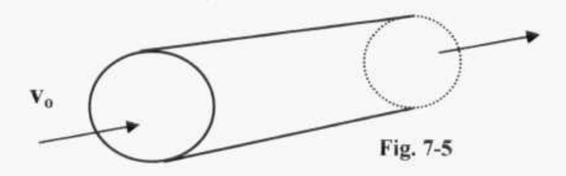


Fig. 7-5

**Considering that the movement of the air mass represents its kinetic energy, the resulting power can be represented by the air mass passing through a given area in one second. Assuming the air mass per time unit is mρ, the density ρ and speed v through the cross section A it results:**

$$m\,\rho = A\rho\ v_0 \qquad (7\text{-}2)$$

**Air mass m passing through across section A, the inherent power P becomes to be :**

$$P = W\rho = 1/2\ m\,\rho\, v_0^2 = (1/2)\, A\,\rho\, v_0^3 \qquad (7\text{-}3)$$

**The air density depends on air composition and pollutants, on air pressure and on temperature (Table 7-1). Its value at sea level and a respective rated pressure of 1013.2 mb and 273 k for clean and dry air will be 1.292 Kg $m^3$. The air composition is nearly constant throughout a layer of the height of 11 km on sea level due to the strong mixing process in the troposphere.**

**Table 7- 1: presents air composition for dry clean air**

| Gas Type | Nitrogen N2 | Oxygen O2 | Argon Ar | Carbon Di-oxid CO2 |
|---|---|---|---|---|
| Volume Content in % | **78.09** | **20.95** | **0.93** | **0.03** |
| Mass Content in % | **75.52** | **23.15** | **1.28** | **0.05** |

**The inherent kinetic energy in moving wind into mechanical energy, wind energy converters (WEC ), which are devices capable of transforming appears on the rotor axis of the WEC. The two existing categories of WECs are characterized by the principle of transformation of wind energy such as lift type WECs and Drag type WECs. It is needed to focus briefly on factors influencing the real obtainable power from the wind stations. It can indicated due to the performance of generation as:**

**1- The angle of inclination of the blades measured to plan of rotation is a decisive factor determining the power coefficient of the WM and hence the effectiveness of the blades to convert the kinetic energy of the wind.**

**2- The effective velocity $V_e$ is the geometric sum of the mean wind speed $V_e = (v_0 + v_a)/2$ and the relative motion of the blade foil. This results a lift force $F_l$ acting on the blade foil described by the formula:**

$$F_l = C_l\ \rho\ V_e^2\ A_l/2 \qquad (7\text{-}4)$$

**Where $C_l$ is the lifting coefficient, ρ the air density, and $A_l$ the area exposed to the lift force at the same time a drag force $F_d$ is acting on the blade profile which can be described by:**

$$F_d = C_d\ \rho\ V_e^2\ A_d/2 \qquad (7\text{-}5)$$

**Where $C_d$ is the drag coefficient and $A_d$ the area exposed to the drag force. It is mainly opposing the movement of the blade.**

## 7-3: Untraditional Sources of Electricity

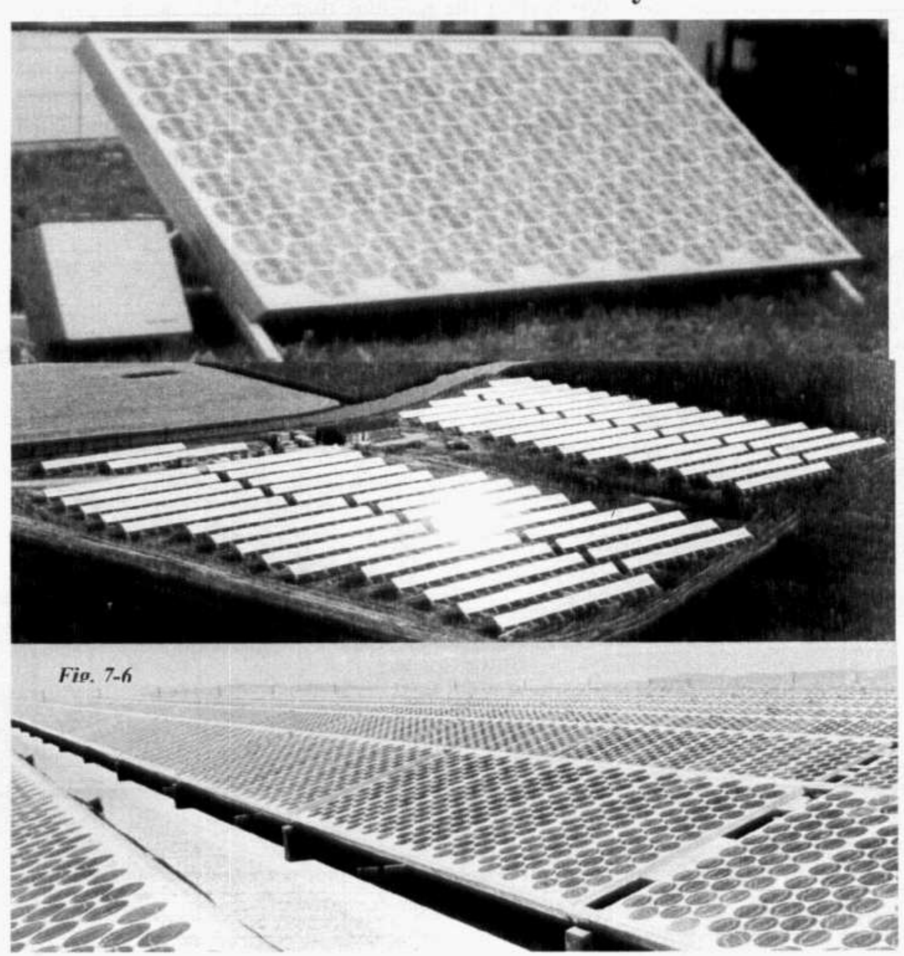


*Fig. 7-6*

Here, the non traditional means the non ordinary type that we use. So, the renewal energy sources as solar energy (See Fig. 7-6) could inserted inside but a new proposal could be remarked in this point. Also, this cell as a group needs to a steel foundation as shown in Fig. 7-7. It is heavy and cost for the stations of solar energy generation.

### I- Electrolysis

This may include some sub-titles to work under a certain rule. This may be mentioned in the few next lines.

#### 1- Photo Strategy

In this process solar panels absorb sunlight and converts it into an electric current directly for use in the electrolysis reaction. It is a costing concept. Currently the cost of efficient solar panels is astronomical, therefore not very practical.

**Currently there are numerous studies as to the feasibility of photo-electrolysis. Numerous institutions are investigating the possible materials that can lower the cost for the solar panels to be used in this process.**

### 2- Wind Style

**The source of electricity for this process is, quite simply, wind. Wind will be harnessed through the use of windmills and power generators. The windmills will power the generators that will then fuel the electrolysis process. At this time there is a study in Southern New York, which, in cooperation with Cornell University, is studying the feasibility of "Wind-Hydrogen Power."**

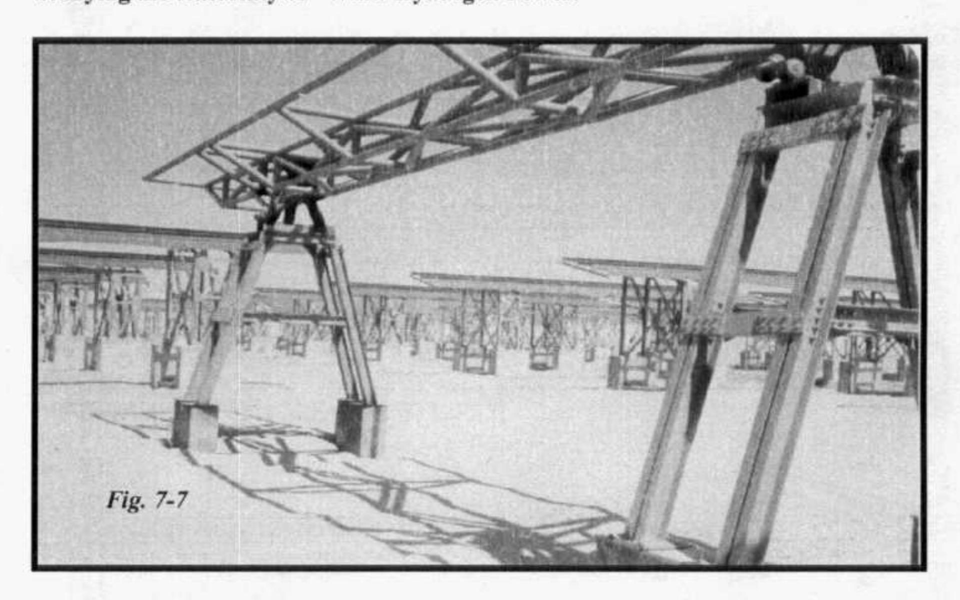


*Fig. 7-7*

### 3- Hydro Technology

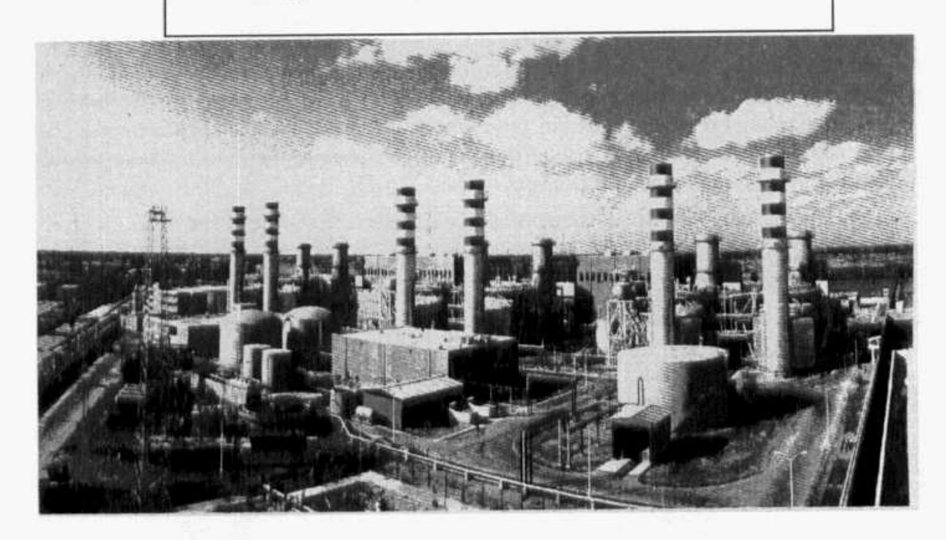
**Hydro Electrolysis entails using hydroelectric power plants to fuel the electrolysis process. It does not as widespread as the above-mentioned processes. Currently Hydroelectric power plants are few and far between.**

## 7-4: Variable Load on Power Station

**The function of a power station is to deliver a continuous power to a large number of consumers at everywhere. However, the power demands of different consumers vary in accordance with their activities and types so that the load on a power station is never constant, rather it varies from time to time. Most of the complexities of modern power plant operation arise from the inherent" variability of the load demanded by the users. Unfortunately, electrical power cannot be stored and, therefore, the power station must produce power as and when demanded to meet the requirements of the consumers. Then, the power engineer would like that the alternators in the power station should run at their rated capacity for maximum efficiency with the wide varied demands. This makes the design of a power station highly complex.**

**A power station is designed to meet the load requirements of the consumers with a difficult construction if it is a thermal type (See Fig. 7-8).**

Fig. 7-8 : (a) A power station with 6 thermal units



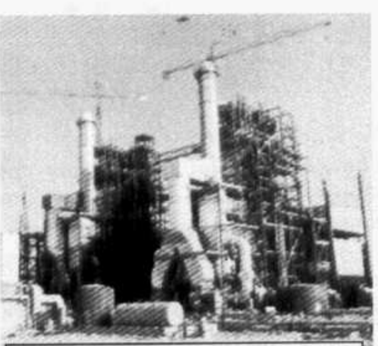


Fig. 7-8 : (b) The unit construction requirements

This means that the station having four generators as in Fig. 7-8 (a) may takes a great part if we show that only the fuel part of the boiler is given in Fig. 7-8 (b). An ideal load on the station, from stand point of equipment needed and operating routine, would be one of constant magnitude and steady duration. However, such a steady load on the station is never realized in actual practice. The consumers require their small or large powers in accordance with the demands of their activities. Thus, the load demand of one consumer at any time may be different from that of the other consumer. This variation do not stand only for a consumer from the others but the load may be varied for the same consumer from time to another or day to other and so on. The result is that load on the power station varies from time to time.

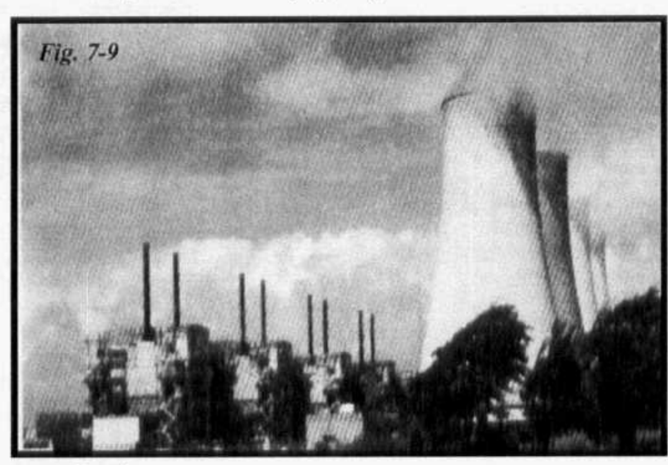
## I- Appeared Requirements

The variable load on a power station and consequentially on the generators in it introduces many perplexities in its operation. This aim should be considered in the process of the design that must be reflected in either the single line diagram or the layout itself. For more importance, some of the basic effects of variable load on a power stations can be tailored as follows.

### 1- Additional equipment

The variable load on a power station necessitates to install additional equipment in the design. For example in steam power stations (Fig. 7-8), air, coal and water are the raw materials for this plant. In order to produce variable power, the supply of

these materials will be required to be varied correspondingly, For instance, if the power demand on the plant increases, it must be followed at the same time by the increased flow of coal, air and water to the boiler in order to meet the increased demand. Therefore, additional equipment has to be introduced in the design to accomplish this job. As a matter of fact, in modern power plants, there is much equipment devoted entirely to adjust the rates of supply of raw materials in accordance with the power demand made on the plant. This big requirements are appeared due to the technological revolution in engineering fields. This takes more efforts for the nuclear power stations (Fig. 7-9).


*Fig. 7-9*

## 2- Energy production cost

The variable load on the plant increases the cost of the production of electrical energy. An alternator operates, usually, at maximum efficiency near its rated capacity. If a single alternator is used, it will have poor efficiency during periods of light loads on the plant. Therefore in practice, a number of alternators with different capacities are installed so that most of the alternators can be operated at nearly full load capacity. However, the use of a number of generating units increases the initial cost per kW of the plant capacity as well as floor area required. This leads to the increase in production cost of energy. This subject may be reflected to the lay out design.

Obviously, a single generating unit (i.e. alternator) will not be an economical proposition to meet this varying load because a single unit will have a very poor efficiency during the periods of light loads on the power station. The selection of the number and sizes of the units is decided according to the annual load curve of the station. The number and size of the units are selected in such a way that they correctly fit the station load curve. Once this underlying principle is adhered to, it becomes possible to operate the generating units at or near the point of maximum efficiency.

# II- The Selection of Units

The selection of number and sizes of the generating units depends on some points, which should be kept in view. They are:

1- The quantity and size of the units should be so selected that they approximately fit the annual load curve of the station.

2- The units should be preferably of different capacities to meet the load requirements. Although use of identical units (i.e. having the same capacity) ensure saving in cost, they often do not meet the load requirement.
3- The capacity of the plant should be made 15 to 20% more than the maximum demand to meet the. future load requirements.
4- There should be a spare generating unit so that repairs and overhauling of the working units can be carried out.
5- The tendency to select a large number of units of smaller capacity, to fit the load curve very accurately, should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.
Section of number and sizes of units : Assuming power factor of the machines to be 0-8, the output of the generating units avail-. able will be 8, 16, 20 and 24 MW. There can be several possibilities. However, while selecting the size and number of units, it has to be borne in mind, for the design base, that:
(a) One set of highest capacity should be kept as standby unit.
(b) The units should meet the maximum demand on the station.
(c) There should be overall economy.
The load duration curve should be considered to cover the performance of the load curve.

## III- Method for meeting the Load

The aim of the design of a station of a part of it is concluded in the covering for any variation of the loads according to the characteristic of the load curves. This design may be considered in the next part.

### 1- Individual Station Design

The total load on a power station consists of two parts *viz.* base load and peak load. In order to achieve overall economy, *the best method to meet load is to interconnect two different power stations.* The more efficient plant is used to supply the base load and is known Method of meeting the Load as *base load power station.* The less efficient plant is used to supply the peak load. There is no fast rule for the selection of base load and peak load stations as it would depend upon the particular situation. For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load station to meet a particular requirement.

### 2- The design as a part of the network

The various problems facing the power engineers are considerably reduced by interconnecting different power stations in parallel. Although interconnection of stations involves extra cost (considering the benefits derived from such an arrangement), it is gaining much favor these days. Some of the advantages of interconnected system (United Power System), in the subject of the station design, may be listed below.

(a) *exchange of peak loads*

An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with.

(b) *Use of older plants*

The interconnected system facilitates the use of older and less efficient plants to carry peak loads of abort durations. Although such plants may be inadequate when used alone, they have sufficient capacity to carry short peaks of loads when

interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

*(c) Economic operation*

The interconnected system makes the operation of concerned power stations, under design, quite economical. It is because sharing of load among the stations is arranged in such a way that more efficient stations work continuously throughout the year at a high load factor and the less efficient plants work for peak load hours only.

*(d) Increases diversity factor*

The load curves of different interconnected stations are generally different so that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. This means that the diversity factor of the system will be improved, thereby increasing the effective capacity of the system.

*(e} Plant reserve capacity*

Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the efficiency of the system and its load factor.

*(f) Reliability of supply*

The interconnected system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.

# Chapter VIII

# INVESTMENT PRINCIPAL

**Engineering economy is the application of certain principles of economics to the problem of investments, principally engineering-related investments. Today this simple definition needs to be expanded considerably, as the subject itself has expanded over the years since the last century. This was happened when Wellington wrote of railway location in the United States. To economics must be added mathematic-and particularly the applied version known as operations research. With more complicated problems, encountered – planning the entire transport system of a developing country, (for example sociology, anthropology, urban planning, and other disciplines) must be combined with economics and mathematics in order to arrive at satisfactory solutions. Although such a comprehensive approach will not be treated in an elementary text. The designer should be aware of the necessity for such multidisciplinary approaches to avoid an overly narrow view of the subject. A food rule is that a broad enough view should be taken, by including disciplines other than engineering and economics, that an optimal solution of the problem can be determined. To clarify this remark, let us imagine a situation in which a cross town freeway is proposed in a major city. The engineering and economic studies completed, the city government is called upon to decide whether the project will be built. A member of the city' government asks a question concerning the effect of the proposed freeway on the form of the city will the project cause the city to spread out even farther, thus increasing transportation distances between working places and residences ? Will the freeway erect barriers to movement across it, create poverty pockets, or bisect existing neighborhoods? Evidently some aspects of the effects of the project have been disregarded . An Urban planner is needed to combine views with those of the engineers and economists so that an optimal solution may even have the opportunity of being discovered.**

## 8-1: Styles of Investments

**There are many types for investments in the fields of construction as electric stations so that we can consider them shortly.**

### 1 – Mutually Investment

**Investments in engineering works are made in order to solve a problem. A river must be crossed, for example. A bridge must therefore be built. Imagine that the alternative designs consist of one in steel and one in reinforced concrete. These are mutually exclusive investments because only on of the alternatives proposed will be built. It would make no sense to build both alternatives. Even clearer is to Be example of a multistory building. Suppose that a selection must be made among plans for different short term plans story building. Only one building of a definite number of stories will be built on the available lot. The other building designs must be rejected. The type of investment – mutually exclusive, mutually independent, of mutually interdependent- is important because different techniques of analysis must be used, depending on the type.**

### a) Mutually Independent Investment

**Transportation of on of the western states is confronted with proposals for a number of highway projects, perhaps running into the hundreds. Building one of them does not in any technical was preclude building another. Some proposals will qualify for construction and be built while others will not. The point is that there is no technical relation the projects that will be built and those for which there will be insufficient funds to build. They will be all mutually independent projects. For another example. Consider an number of projects proposed by the engineering department of a large refinery. Selection of a certain project, of a number of projects, to be constructed will not in any technical way affect any of the other projects. Again, these are independent projects.**

**Usually an list of proposed projects is presented with the supposition that not all the projects on an list will be built because available funds will not suffice to cover the cost of the whole list. A capital budget must normally be met. Therefore, certain projects on the list will be built, and others will not; but the total cost of those that are constructed must fall within the limitations of the money available (budget). The process of selecting projects to be approved for construction is known as capital budgeting.**

**A method of rigorous analysis in capital budgeting is zero-one integer programming, a specialized case of linear programming. The techniques used in the analysis of alternatives form the foundation of the process, and these are Incorporated into the integer programming analysis in order to arrive at on optimal set of projects to be included in a budget.**

### b) Mutually Interdependent Investment

**projects may also be mutually interdependent. For example, take machinery and the buildings to house it. The machinery and its buildings must be analyzed together, if an investment in one assumes an investment in the other. On the other hand, they may be analyzed separately, because even though the machinery cannot be properly used without buildings to house it, the buildings themselves may have other uses, as warehouses.**

## 2- private Investment

**Mention has been made of the division of an economy into the public and private sectors and investments under the same classifications, depending on the source of funds of the projects concerned. Investments may be characterized by identifiers other than the source of funds for their construction. Private investments are controlled by private persons and private firms for private gain. A company, for example, is considering the replacement of a production lathe with another, more efficient modern model. No question of any public good or evil that may be brought about by the purchase of the lathe is entertained. The only point considered is the effect of the new lathe on the profits of the company This is as it should be, if the officers of the company are to fulfill their obligations to the stockholders. The attitude taken here is characteristic of investment in the private sector.**

**Along with ignoring all effects except those that affect its pocketbook, the private sector accepts prices as given by the economy. Normally, no consideration of shadow prices- the true societal cost of on input to an investment – is given Even in**

countries where enormous labor resource unemployment exists, the cost of labor is taken given by the labor market, the price system's perfect operation is assumed. Private sector investments are not generally infrastructural; that are not concerned with investment in roads, of education, or the judicial system, or any other area whose purpose is to give support to the operation of a society.

## 3- Public Investment

Public investment covers such a wide range – from a country program to a county bridge that it is difficult to define exhaustively. Its main characteristic, already mentioned, is that its finding is public. Some other points of difference between public and private investments may help to clarify their nature. In public investment, the desired end result is the society. A county bridge benefits the local community. The gainer from both programs is the public. The relative difficulty of estimating that gain is evident immediately as we compare public investment to private.
Public investment is sometimes on a much grander scale than the private sector can manage. River development projects like the Nile in Egypt are for beyond the capacity of private companies- of indeed, their interest. For such grand schemes, we have an element of risk that private companies are unwilling to accept. Political realities often rule out participation in large projects by private companies. A change of regime can cause abandonment of support for a project wit such attendant losses as only a government can stand. This is not to say that all large projects must be performed by governments. There is no doubt, however, that governments tend to take on larger projects than private, firms generally do.
Infrastructural projects are almost always public. The sewer system of a city is the public's concern, and so are its streets. Roads and highways, the educational and judicial systems, and all their buildings are almost al public. Ports and airports are largely publicly owned and operated. National defense establishments and their many projects are in the public sector. Most of what provides transport, education, judicial service, and security of persons and the nation is public. No rule for judging what should be public and what should remain in the private sector will be advanced here. Analysis of public projects requires a judgment of the state of health of the price system because public projects must be judged by social costs and social benefits. When costs and given by the price system are not the same ad social costs adjustments to that system must be made if fair economic and social comparisons of alternatives and budgets are to be made.

## 4- Engineering Economic Decision

Suppose that you even hold same shares in a company, which also makes you one of the company's many owners. What objectives would you set for the company? While all firms are in business in hopes of making a profit, what determines the market value of a company is not profits per Se, but cash flow, It is, after all, the available cash that determines the future investments and growth of the firm. Therefore, one of your objectives should be to increase the company's value to its owners (including yourself) as much as possible. The market price of your company's stock to some extent represents the value of our company. Many factors affect your company's market value: present and expected future earnings, the timing and duration of these earnings, as well as the risk associated with them. Certainly; any successful investment decision will increase the company's market

value, The stock price can be a good indicator of your company's financial health and may also reflect the market's attitude about how well our company is managed for the benefit of its owners. In the case of a private company, the firm's financial position prior to and after introducing the sensor to the market was as presented in Table 8-1.
From Table 8-1 it is seen that a company sales at 1990 were 4.34 billion $. The value of 3.67 billion $ of assets its owns but the 2.81 billion $ of liabilities owes to creditors, were necessary to support these sales. The 0.86 billion $ of net worth indicates the portion of the company's assets that was provided by the investors (owners or stockholders). The company had earnings of 36 y9 million $ but only 310.6 million $ available to common stockholders (after paying out 57.3 million $ in cash dividends to its preferred stockholders). It had about 96.06 million shares of common stock, so the company earned 3.20 $ per share of stock outstanding This earnings per indicates an increase of 19% compared with that of 1989.

**Table 8-1 A Company results at the end of 1990 relative to 1989 (in Thousands of dollars, except per share amounts)**

| Year | 1990 | 1989 |
|---|---|---|
| Net sales ($) | 4,344,600 | 3,818,500 |
| Net income ($) | 367,900 | 284,700 |
| Earning per share ($) | 3.20 | 2.70 |
| Total assests ($) | 3,671,300 | 3,114,000 |
| Total liabilities ($) | 2,805,900 | 2,444,000 |
| Net worth ($) | 865,400 | 670,000 |
| Stock price ($) | 633/4-431/8 | 493/4-331/8 |

It is known that investors liked the new product, resulting in increased demand for the company's stock This, in turn, caused stock prices, and hence shareholder wealth, to increase. In fact, this new , heavily promoted, high- tech Sensor razor out be a smashing success and contributed to sending a Company's stock to an all-time high in early 1990. This caused a Company's market value to increase about 20% during the first six-month period. Any successful investment decision on sensor's scale will tend to increase the firm's stock prices in the marketplace and promote long-term success, Thus, in making a large – scale engineering project decision, we must consider its possible effect on the firm's market value.

## 8-2: CASH-FLOW DIAGRAMS

This chapter is directed to the economic evaluation for a design according to the economic point of view. This leads to the main definitions related to as they are tailored as:

1- Alternative, evaluation criterion, intangible factors, time value of money, interest, and principle value.

2- Interest rate and interest period and the interest that has been accrued in one interest period, given the principal and the interest rate or total amount.

3- Equivalence and the amount of money equivalent to a present sum , some the future or past date of equivalence, and the interest rate per year at

which different sums separated by one year are equivalent. This must explain how different loan repayment schemes can be equivalent allowing different repayment schedules for a given principal, interest rate, and time period.

4- Simple and compound interest as well as the total amount of money accrued after one or more years using simple and compound interest methods, when the annual interest rate and the original principal are known.

5- Determination of the fundamental economy symbols P, F, A, n, and i.

6- Determination of the end of period convention and construction of the cash flow diagram.

## 1- Basic Terminology

Before we begin to develop the terminology and fundamental concepts upon which engineering economy are based , it would be appropriate to define what is meant by *engineering economy*. In the simplest terms, engineering economy is a collection of mathematical techniques which simplify economic comparisons. With these techniques a rational, meaningful approach for evaluating the economic aspects of different methods, (accomplishing a given objective), can be developed. Engineering economy is, therefore, a decision assistance tool by which one method will be chosen as the most economical one.

In order for you to be able to apply the techniques, however, it is necessary for you to understand the basic terminology and fundamental concepts that form the foundation for engineering-economy studies. Some of these terms and concepts are described below.

An alternative is a stand alone –solution for a given situation. We are faced with alternative in virtually everything we do, from selecting the method of transportation we use to get to work every day to deciding between buying a house or renting one. Similarly, in engineering practice, there are always several ways of accomplishing a given task, and it is necessary to be able to compare them in a rotational manner so that the most economical alternative can be selected. The alternatives in engineering considerations usually involve such items as asset purchase cost (first cost), the anticipated life of asset ,the yearly costs of maintaining the asset (annual maintenance and operating cost),the anticipated asset resale value (salvage value), and interest rate. After the facts and all the relevant estimates have been collected, an engineering economy analysis can be conducted to determine which is best from an economic point of view. It should be clear that in most instance , if there were not alternative ways of accomplishing a particular task, there would be no need for an engineering economy analysis.

The procedure developed in this chapter will enable you to make accurate economic decisions (according to the given parameters) when one or more alternatives are being considered. What these procedures will not do, however, is helping you to identify what the alternatives are. It should be understood that unless the alternative which is actually the most economical one is *recognized as an alternative*, there is no way that it can be selected, no matter what analytical techniques are used. Thus, the importance of alternative identification in the decision-making process can not be overemphasized, because it is only when this aspect of the process has been thoroughly completed that the analysis techniques presented in this book can be of greatest value.

In order to be able to compare different methods of accomplishing a given objective, it is necessary to have an *evaluation criterion* that can be used as a basis for judging the alternatives. In engineering economy, dollars are used as the basis for comparison.

Thus, when there are several ways of accomplishing a given objective, the method that has the lowest overall cost is usually selected .however in most cases, the alternatives involve *intangible factors*, such as the effect of a process change on employee morale, which can not be expressed in terms of dollars. When the alternatives available have approximately the same equivalent cost, the no quantifiable, or intangible, factors may be used as the basis for selecting the best alternative. For items and alternative which can be quantified in terms of dollars, it is important to recognize the concept of the time value of money. It is often said that money makes money.

The statement is indeed true, for if we elect to invest money today (for example, in a bank or savings and loan association), by tomorrow we will have accumulated more money than we had originally invested. This change in the amount of money over a given time period is called *time value of money*, it is the most important concept in engineering economy. You should also realize that if a person or company finds it necessary to borrow money today, by tomorrow more money than the original loan will be owed. This fact is also explained by the time value of money.

The manifestation of the time value of money is termed interest, which is a measure of the increase between the original sum borrowed or invested and the final amount owed or accrued. Then, if you invested money at some time in the past, the interest would be

**Interest = total amount accumulated - original investment**

**(8-1)**

On the other hand, if you borrowed money at some time in the past, the interest would be:

**Interest = present amount owed - original loan (8-2)**

In either case, there is an increase in the amount of money was originally invested or borrowed, and the increase over the original amount is the interest. The original investment or loan is referred to as principal.

## 2- Interest Calculations

when interest is expressed as a percentage of the original amount per unit time, the result is an interest rate. This rate is calculated as follows:

**interest rate % = ( interest accrued per unit time /original amount ) *100% (8-3)**

Where the most common time period used for expressing interest rates is one year. However, since interest rates are often expressed over periods of time shorter than one year (i.e., 1%per month), the time unit used in expressing an interest rate is termed an interest period. The following examples illustrate the computation of interest rate.

## EXAMPLE (8-1):

The Get - Rich - Quick(G R Q) company invested \$ 100,000 on May 1 and withdrew a total of \$ 106,000 exactly one year later. Compute:

(a) The interest gained from the investment
(b) The interest rate from the investment.

**SOLUTION**

Using E q. (8-1), we get:
Interest = 106,000 - 100,000 = $6000
Equation (8-3) is used to find
percent interest rate = 6000/year /100,1000 *100 % =6 %per year
Comment for borrowed money, computations are similar to those shown above except that interest is computed by Eq. (8-2), for example ,if G R Q borrowed $ 100,000 now and repaid $ 110,000 in one year, using Eq. (8-2), we find that interest is $ 10,000 and the interest rate from E q. (8-3) is 10 % per year.

## 3- Simple and Compound Interest

The concept of interest and interest rate are required to calculate for one interest period past and future sums of money equivalent to a present sum (principal). when more than one interest period is involved, the terms *simple* and *compound* interest must be considered.
Simple interest is calculated using the principal only, ignoring any interest that was accrued in Preceding interest periods. The total interest can be computed using the relation

**Interest = (principal) (no. of periods) (interest rate) = $P_{in}$ (8-4)**

## Example (8-2):

If you borrow $1000 for 3 years at 6%-per-year simple interest ,how much money will you owe at the end of 3 years

**Solution**

The interest for each of the 3 years is
Interest per year = 1000 (.06) = $ 60
Total interest for 3 years from Eq.(8-4) is
Total interest = 1000 (3)(.06) =$ 180
The amount due after 3 years is
1000 + 180 = $ 1180
The $ 60 interest accrued in the first year and the $ 60 accrued in the second year did not earn interest. The interest due was calculated on the principal only. The results of this loan are tabulated in Table 8-1. The end-of-year figure of zero represent the present, that is, when the money is borrowed.

**Table 8-2: Simple-interest computation**

| 1 | 2 | 3 | 4 = (2) +(3) | 5 |
|---|---|---|---|---|
| end of year | Amount borrowed $ | interest $ | Amount owed $ | Amount paid $ |
| 0 | 1000 | 60 | 1060 | 0 |
| 1 | | 60 | 1120 | 0 |
| 2 | | 60 | 1180 | 1180 |

A payment is made by the borrower until the end of year 3. Thus, the amount owed each year increases uniformly by $ 60, since interest is figured only on the principal of $ 1000.

## 4- Symbols

The mathematical relations used in engineering economy employ the following symbols:

P = Value or sum of money at a time denoted as the present; dollars

F = Value or sum of money at some future time; dollars

A = A series of consecutive, equal, end-of-period amounts of money; dollars per month, dollars per year

n = Number of interest period; months, years

i = Interest rate per interest period; percent per month, percent per year.

The symbols P and F represent single-time occurrence values. Symbol A occurs each interest period for a specified number of periods with the same dollar value. The units of the symbols aid in clarifying their meaning. The present sum p and future sum f are expressed in dollars; A is referred to in dollars per interest period. It is important to note here that in order for a series to be represented by the symbol A where it must be uniform (i.e., the dollar value must be the same for each period). Uniform dollar amounts should be extended through *consecutive* periods. Both conditions must exist before the dollar value can be represented by A. Since n is commonly expressed in years, A is usually expressed units of dollars per year. The compound interest rate i is expressed in percent per interest period. For example, 5% per year. Except where noted otherwise, this rate applies throughout the entire n years or n interest periods. The most common engineering-economy problems involve the use of n and i and at least two of the three terms, P, F, and A. the following example illustrate the used symbols.

## 5- Diagrams

A person or a company has cash excepts (income) and cash disbursements (costs) which occur over a particular time span. These receipts and disbursements in a given time interval are referred to as *cash flow*, wit positive cash flows usually representing receipts and negative cash flows representing disbursements. At any point in time, the net cash flow would be represented as

$$\text{Net cash flow} = \text{receipts} - \text{disbursements} \qquad (8\text{-}5)$$

Since cash flow normally takes place at frequent and varying time intervals within an interest period , a simplifying assumption is made that all cash flow occurs at the end of the interest period. This is known *as end-of-period convention*. Thus, when several receipts and disbursements occur within a given interest period, the net cash flow is assumed to occur at the end of the interest period. However, it should be understood that although the dollar amount of F or A are always considered to occur at the end of the *interest period*, this does not mean that the end of the period is December 31. in the situation. For example, since investment took place on May 1, 19 84, the withdrawals will take place on May 1, 19 85, and each succeeding May 1 for 10 years (the last withdrawal will be on May 1, 1994, not 1995). Thus, end of the period means one time period from the date of the transaction (whether it be receipt or disbursement). Next chapter the equivalent relations between P, F and A values at different times will be explained.

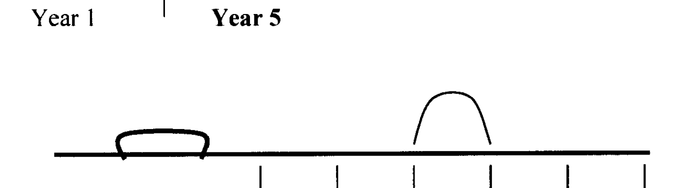



**Fig. 8-1: A typical cash flow time scale**

**A *cash-flow diagram* is simply a graphical representation of cash flows drawn on a time scale. The diagram should represent the statement of the problem and should include given parameters and what is to be found. That is, after the cash-flow diagram has been drawn, an outside observer should be able to work with the problem by looking at only the diagram. Time 0 is considered to be present and time 1 the end of time period 1(assume that the periods are in years unit). The time scale of Fig. 8-1is set up for 5 years. since it is assumed that cash flows occur only with the times marked 0, 1, 2, .....,5. the direction of the arrows on the cash-flow diagram is important for the problem solution. Therefore, a vertical arrow pointing up will indicate a positive cash flow. Conversely, an arrow pointing down will indicate a negative cash flow. The cash-flow diagram in Fig. 8-1 illustrates a receipt (income) at the end of year 1 and a disbursement at the end of year 2. It is important that you thoroughly understand the meaning and construction of the cash-flow diagram, since it is a valuable tool in problem solution.**

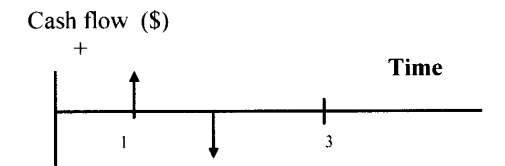



**Fig. 8-2: Positive and negative cash flow**

## 8-3: Cost Reduction

**Firstly, new ideas of a designer come from many different levels in the organization. Since some ideas will be good while others will not, we need to establish procedures for screening projects. Many large companies have a specialized project analysis division that actively searches for new ideas, projects, and ventures. Once project ideas are identified, they can be typically classified as:**

**(1) material and process selection,**
**(2) equipment replacement,**

(3) new product and product expansion,
(4) cost reduction,
(5) service improvement.

This classification scheme allows management to address key questions. Can the existing plant, for example, be used to achieve the new production levels? Does The station have the knowledge and skill to undertake this new investment? Does the new proposal warrant the recruitment of new technical personnel? The answers to these questions help stations screen out proposals that are not feasible given the resources.

In general, the larger the investment, the more detailed is the analysis required to support the expenditure. For example, expenditures to increase out put of existing products, of to manufacture a new product, would invariably require a very detailed economic justification. Final decisions on new products and marketing decisions are generally made at a high level within the company. On the other hand, a decision to repair damaged equipment can be made at a lower level within the company.

At the level of plant operations, engineers must make decisions involving materials plant facilities, and the in-house capabilities of station personnel. Let us consider as an example the manufacture of food-processors. In terms of material selection, selection, several parts could be made of plastic while others must be of metal. Once materials have been chosen, engineers must consider the production methods, the shipping weight, and the method of packaging necessary to protect the different types of material. In terms of actual production parts may be made in-house or purchased from an outside vendor. The decision as to which parts to produce in-house depends on the availability of machinery and labor. If the project expects to produce the product for many years, it may be advantageous to purchase the required machinery and produce the product in-house. This is a class of engineering decision problems that involve selecting the best course of action when there are several ways to meet the projects, requirements. The choice often turns on which item is expected to generate the largest savings (or return on the investment).

## Example (8-3)

Engineers at General Motors want to investigate alternative materials and processes for the production of automotive exterior body panels. The engineers have identified two types of material: sheet metal and glass fiber reinforced polymer, known as plastic sheet molding compound (SMC), as given in Table 8-3 Exterior body panels are traditionally made of sheet. With a low material cost, this sheet metal also lends itself to the stamping process, a very high- volume, proven manufacturing process. On the other hand, reinforced polymer easily meets the functional requirements of body panels (such as strength and resistance to corrosion). There is a considerable debate among engineers as to the relative economic merits of steel as opposed to plastic panels. Much of the debate stems from the dramatically different cost structures of the two materials

**Table 8-3 : Sheet molding compound process**

| Description | Plastic SMC | Steel Sheet Stock |
|---|---|---|
| Material cost ($/Ib) | 0,75 | 0,35 |
| Machinery investment (million $) | 2,1 | 24,2 |
| Tooling investment (million $) | 0,683 | 4 |
| Cycle time (min/part) | 2,0 | 0,1 |

Since plastic is petroleum based, it is inherently more expensive than steel. The plastic-forming process involves a chemical reaction and if has a slower cycle time. However, both machinery and tool costs for plastic are lower than steel due to the relatively low forming pressures, lack of tool abrasion, and single-stage pressing involved in handling. Thus, the plastic would require a lower initial investment but would be higher material costs. The choice of material will dictate the manufacturing process for the body panels. Many factors will affect the ultimate choice of the material, and engineers should consider all major cost elements, such as machinery and equipment, tooling, labor, and material. Other factors may include press and assembly, production and engineered scrap, the number of dies and the cycle times for various processes .

Then, a cost-reduction project is one that attempts to lower the firms operating costs. Typically we need to consider whether we need to consider whether we should buy equipment to perform an operation now done mannally- of spenf money now in order to save money later. The expected future cash inflows on this investment are savings resulting from lower operating costs.

## Example (8-4)

A trucking company, has begun installing satellite systems linked to Geostar on 2000 trucks. Vehicles linked by such services carry a keyboard and display and transmission equipment about the size of a car battery. Drivers type in messages, which are bounced of a satellite and received by ground stations operated by the satellite company. The ground stations then the information by telephone line to the customer's home office. In tests last year on 120 trucks, Burlington concluded that the technology yielded direct gains to its bottom line. The company found that satellite messaging could cut 60% from its 5 million $ bill for long-distance communications with drives . More important the drivers reduced the number of' deadhead ' miles- those driven without paying load- by 0.5% Applying all that improvement to all 230 million miles covered by the Burlington fleet cash year would produce an extra I,25 million $ of profits. With innovation in transmission technology and miniaturization, the cost of satellite terminals has fallen in the last few years from about 20,000 to 4000$ . Equipping 2000 trucks with the satellite transmitters will cost 8 million $ (2000X4000$) In addition it is reasonable to

suppose that construction of a message relaying system will cost about 2 million $ for a total initial investment of 10million $. Expected annual savings are 4,20 million $ (3milion $ in savings on long- distance communication plus 1.25 million $ on deadhead miles).

The labor component becomes considerably more accurate for a preliminary estimate because of the additional engineering which has been completed on the project. When the process flow sheets are complete, the bulk accounts better defined, the utility requirements known, the control loops counted, etc. It is giving a much improved basis for the estimation of work hours. Good planning and scheduling is an absolute where it must be proper for utilization of construction labor. Unless great care is exercised in planning the work, the labor will not be utilized to get even average productivity from a construction labor force.

The bulk accounts for a preliminary estimate are also improved over those for a factored estimate. Either the estimate of the factors is improved or a preliminary takeoff has been made which allows a considerably improved estimate of work hours for each account. The bulk accounts which are frequently under estimated for a processing plant are piping, electrical (including instrumentation), and concrete. Therefore, the aforementioned accounts need to be defined well as early as possible in the evolution of a project. Work hours for setting equipment wick at times be estimated by the vendor. Vendor estimates tend to be low while contractor estimates tend to be high. Do not get into a confrontational situation but rather promote understanding between the parties for a more harmonious working situation and a reasonable estimate of the actual work hours required Engineering and home office work hours may be better estimated because of advances in engineering and planning for the project. Since process flow-sheets and other engineering documents are available, an accurate estimate of engineering and home office hours should be possible at this time in the evolution of a project.

One of the most difficult tasks on a project is providing sufficient planning to allow a breakdown of work into small day-to-day work packages, that facilitate the proper utilization of construction crews. The lack of such planning is absolutely the fault of the construction management. Labor planning requires detailed scheduling with time constraints and labor loading for each day of the project duration. This allows an orderly buildup of crafts and labor as well as an orderly buildup of the capital cost estimate.

Craft and labor leveling simply entails taking the total contingent of people on the job at any particular time during the construction of the project and making sure that demand and supply match. For example, the work for the pipe fitters must be planned to allow an orderly buildup, utilization at peak demand, and then an orderly reduction of the craft force at the and of the project. Scheduled overtime is counterproductive and can result in substantially increased costs with no net gin in productivity. In fact, sustained scheduled.

# Chapter IX

# ANNULAL COST EVALUATION

**The primary methods for calculation of the *equivalent uniform annual-cost* (EUAC) of an asset may be needed to determine the station cost under design. The better of two alternatives according to the annual-cost comparison can be based and then selected. The alternative selected using (EUAC) must be the same as that chosen using present- worth or any other evaluation method; that is, all methods should result in identical decisions, just in a different manner.**

**This chapter deals with some fundamental subjects as tailored below.**

**1- Why the EUAC must be calculated for only one cycle of each alternative, when the alternatives have different lives.**

**2- Calculating the EUAC of an asset having a salvage value, using the salvage sinking fund method, given the asset initial cost, salvage value, life, and interest rate as said in the past chapter.**

**3- Exception of using the capital- recovery- plus –interest method.**

**4- Choice of the better of two alternatives on the basis of their EUAC, given their initial costs, salvage values, lives, amount and time of the operating costs, and interest rate.**

**5- Evaluation of the EUAC of a perpetual investment, given the initial cost of the asset, amount and timing of disbursements, and rate.**

**These problems may be effective with the next paragraphs.**

## 9-1 Period with Different Lives

**EUAC (equivalent uniform annual cost) is another method that is commonly used for comparing alternatives. As illustrated , the EUAC means that all disbursement (irregular and uniform ) must be converted to an equivalent uniform annual cost, that is, a year-end amount which is the same each year. The major advantage of this method over the same number of years when the alternatives have different lives. When the EUAC method is used, the equivalent uniform annual cost of the alternative must be calculate for one life cycle only. Thus, as its name implies, the EUAC is an equivalent annual cost over the life of the project. If the project is continued for more than one cycle, the equivalent annual cost for the next cycle and all succeeding cycles would be exactly the same as for the first, assuming all cash flows were the same for each cycle. The EUAC for one cycle of an alternative therefore represents the equivalent uniform annual cost of that alternative forever.**

## 9-2: Salvage Sinking (Fund Method)

**When an asset of a given alternative has a terminal salvage value (SV), there are several ways by which the EUAC can be calculated. This section presents the salvage sinking fund method, probably the simplest of the three discussed in this chapter. This is the method that is used hereinafter. In the salvage sinking-fund method, the initial cost (p) is first converted to an equivalent uniform annual cost using the A/p (capital-recovery) factor .the salvage value, after conversion to an equivalent uniform cost via first cost. The calculations can be represented by a general equation:**

| $EUAC = p(A/p, i\%, n) - sv(A/F, i\%, n)$ | (9-1) |
|---|---|

Naturally, EUAC is nothing more than an A value, but it is referred to as EUAC here.

## Example (9-1):

calculate the EUAC of a machine that has an initial cost of $8000 and a salvage value of $500 after 8 years. Annual operating costs (AOC) for the machine are estimated to be $900, and the interest rate of 6% is applicable.

**SOLUTION**

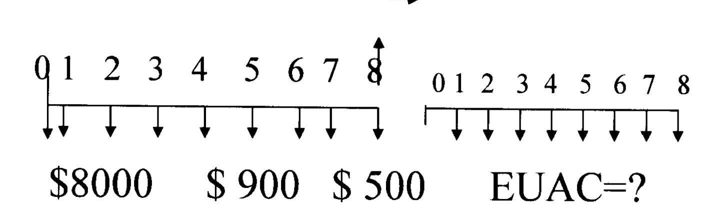
The cash-flow dig ram (Fig.9-1) requires the value of EUAC

**EUAC = A1 + A2**

Where A1 = annual cost of initial investment lees salvage value ,E q. (9-1)

**A2 = annual maintenance cost = $ 1238**

**EUAC =1238 + 900 = $ 2138**




(a) dig ram for machine costs (b) conversion to an EUAC

Fig. 9-1

Comment since the maintenance cost was already expressed as annual cost over the life of the asset, no conversions were necessary. The simplicity of the salvage sinking-fund method should be obvious form the straightforward calculations shown in this example. The steps in this method are the following:

1-annualize the initial investment cost over the life of the asset using the A/p factor.
2-Annualize the salvage value using the A/F factor.
3-Subtract the annualized salvage value form the annualized investment cost.
4-Add the uniform annual costs to the value from step 3.

## 9-3 Salvage Present (Worth Method)

The salvage present-worth method is the second method by which investment costs having salvage values can be converted into an EUAC. The present worth of the

salvage value is subtracted from the initial investment cost, and the resulting difference is annualized for the life of the asset. The general equation is

$$EUAC = [p - sv\,(p/f, I\,\%, n)](A/p, I\,\%, n) \quad (9\text{-}2)$$

The steps that must be followed in this method are the following:
1- Calculate the present worth of the salvage value via the p/f factor.
2- Subtract the value obtained in step 1 from the initial cost p.
3- Annualize the resulting asset difference using the A/p factor.
4- Add the uniform annual costs to the result of step 3.

## Example (9-2):

Compute the EUAC for the machine detailed in Example 9-1 using the salvage present-worth method.

### Solution

Using the steps outlined above and Eq .(9-2),

$$EUAC = [\,8000 - 500(p/f, 6\%, 8)]\,(A/p, 6\%, 8) + 900 = \$\,2138$$

## 9-4: Capital-Recovery-Plus (Interest Method)

The final procedure that will be here for calculating the EUAC of an asset having a salvage value is the capital-recovery-plus-interest method. The general equation for this method is

$$EUAC = (p - sv)(A/p, i\%, n) + sv(i) \quad (9\text{-}3)$$

In subtracting the salvage value from the investment cost before multiplying by the A/p factor, it is recognized that the salvage value will be recovered. However, the fact that the salvage value will not be recovered for n years must be taken into account by adding the interest (SVi) lost during the asset' s life. Failure to include this term would assume that the salvage value was obtained in year 0 instead of year n. Only 5 steps should be followed for this method as follows:
1- Subtract the salvage value from the initial cost.
2- Annualize the resulting difference with the A/P factor.
3- Multiply the salvage value by the interest rate.
4- Add the values obtained in steps 2 and 3.
5- Add the uniform annual costs to the result of step 4.

## Example 9-3:

Use the value of Example 9.1 to compute the EUAC using the capital-recovery-plus-interest method

### Solution

From E q. (3.3) and the steps above,

$$EUAC = (800 - 500)(A/p, 6\%, 8) + 500(.06) + 900 = \$2138$$

Since results do not depend on the used method, it would be good procedure hereafter to apply only the simplest one in order to avoid unnecessary errors caused by mixing the methods. Then, the salvage sinking fund method would be implemented.

## 9-5: Comparing Alternatives by EUAC

The equivalent-uniform-annual-cost method of comparing alternatives is probably the simplest of alternative evaluation techniques. Selection is made on the basis of EUAC with the alternative having the lowest cost being the most favorable. Obviously no quantifiable data must also be considered in arriving at the final decision, and generally, the alternative having the lowest EUAC should be selected. Perhaps the most important rule to remember when making EUAC comparisons is that *only one cycle* of the alternative must be considered. This assumes, of course that the costs in all succeeding periods will be the same. While it is true that the cost of an asset today will portly be much lower than the cost of the same asset 10 years from today because of inflation. It must be remembered that, usually, the costs of the other alternatives would increase as well. The analytical methods presented here are mainly for the purpose of making comparisons not for determining actual costs while the same evaluation would be reached. This would be at any future date as long as all costs increased proportionality. Obviously, when information is available as the costs of certain assets will increase or increase considerably. Because of technical improvements or increased competition, these factors must be taken into consideration in the final decision.

### Example 9-4:

The following costs are proposed for two equal-service tomato peeling machines in a food canning plant:

Table 9-1: The deduced values

| Item | Machine A | Machine B |
|---|---|---|
| First cost ($) | 26000 | 36000 |
| Annual maintenance cost ($) | 800 | 300 |
| Annual labor cost ($) | 11000 | 7000 |
| Extra income taxes ($) | ...... | 2600 |
| Salvage value ($) | 2000 | 3000 |
| Live years | 6 | 10 |

If the minimum required rate of return is 15% which machine should be selected?

### Solution:

The cash-flow diagram for each alternative is shown in Fig. 9-2 where the EUAC of each machine using the salvage sinking-fund method can be derived with the help of Eq. (9-1) in the form:

$$0 = -P + \sum_{t=1}^{n} CFt\,( P/F,\ I\ \%\ , t) \qquad (9\text{-}4$$

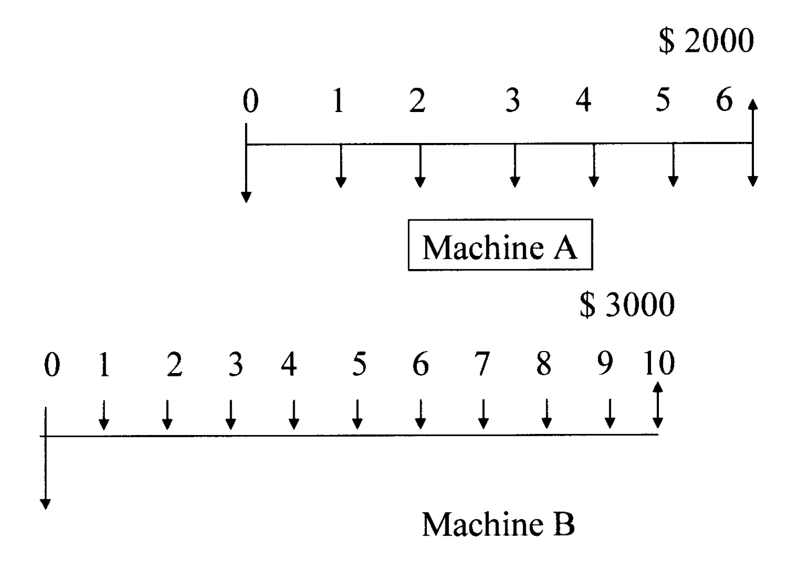



Fig 9.2

Select machine b, since EUAC (B) < EUAC (A).
Years n before the first cost and stated return is realized, that is, for each alternative determine the n value such that
The alternative with the smaller n value is selected. If I = 0 % , the no return payback period is computed. Comparison using payback-period analysis may give a different result than doe's present-worth or EUAC analysis because it neglects all each flows after the time n and it also overlooks the time value of money if I = 0 %.

## 9-6: EUAC of a Perpetual Investment

Sometimes it is necessary to compare alternative that can be expected to have a perpetual life, such as flood-control dams or irrigate projects. In the presented analysis, it is important to recognize that annual cost of perpetual initial investment is simply the annual cost interest on the initial lump sum. That is, if the government invests $ 10000 in a certain public work project, the EUAC of the investment would be $ 10000 (0.04) = $ 400 for interest rates of 4 %. This computation is easy to understand when it is realized that the government could let an investor pay the $ 10,000 for the public works project. Then, it pays the investor the $ 400 per year for ever. If the interest rate is 4 % since both persons would receive only $ 400 per year perpetually costs recurring at regular or irregular intervals. This will be handled exactly as conventional EUAC problems as all other

costs must be converted into equivalent uniform annual costs for one cycle. They are thus automatically annual costs for ever as discussed above.

## 9 –7 : GRAMMARLESS LOSSES

Nowadays , the fuel consumption is floating on the surface of the most important problems in the world so that all efforts were directed towards the saving of the traditional energy sources which appear to be the simple used one. On the other hand, the renewable energy is strongly introduced into the field of energy sources to be utilized either beside or instead of traditional types. Both time and effort of Scientists on Globe are concentrated for this purpose to minimize the energy loss. The traditional energy produce a lot of pollution materials and substances that pollute the environments surrounding our life . Although the spread utilization of such item , the need for a new type of energy generation would be introduced to replace the polluted area by another clean. However , the utilization of energy sources must be an economic problem to decide its use where the traditional fuel is still the most economic one.

The required concept to cover the suggested problem can be appeared in the coding process utilized the consumed energy. Otherwise, it is needed to managing the problem of utilization of energy. This means that we must control the energy consumption in the network either though the generation or in the transmission or even in the distribution systems of the network .

## I - MATHEMATICAL ANALYSIS

It is known that there is a minimum value for energy loss in networks where the parameters of the circuit consume it and it is defined as the technical loss . It takes different shapes in the various stages of a network such as generation, transmission, distribution and the utilization principle.

Alternatively, the generated loss may depend mainly on the type and fuel but this differs for the transmission section where the great effect included in the reactive power generated in the network and consequently active and reactive power losses may be formulated mathematically. It is known for the active power loss although the reactive power loss can play a great role. *The equivalent circuit Π* for transmission lines presents that the loss will be a function of the circuit parameters as inductive reactance ($X_L$), capacitive reactance ($X_c$) and the resistance R.

The loss must appear as reflected by the power factor triangle as both active and reactive loss can be included together when the reactive power loss depends on the harmonic presence as well as the inductive and capacitive parts of the given circuit.

The transmission system is the most economic part of a network due to the high level of transmitted voltage level in order to decrease the loss. Although the transmission loss is minimized in this part of the network , the loss in the reactive power appears to be the main goal. This leads to the important of improvement of power factor in transmission systems of a network. Therefore, the loss in transmission and distribution parts can be tailored into two fundamental items as active and passive where the active loss ( PL ) means the actual consumption and it is expressed through:

$$PL = I * R \qquad (9\text{-}5)$$

Also, the reactive loss (QL) according to the equivalent circuit may be deduced in the form :

$$QL = (Iz)^2 * X_L + ((I_{c1})^2 + (I_{c2})^2) * X_c / 2 \qquad (9\text{-}6)$$

Whatever, the control angle plays a great role in this concern as assuming that both terminal voltages ($V_1$) and ($V_2$) are equal. This means that also both values of ($I_c$) are equal, and leading to a simple formula for the passive loss as a ratio to the sending end power (S) as

$$\frac{QL}{S} = \frac{Ic^2 * X_c + Iz^2 * X_L}{V * I} \qquad (9\text{-}7)$$

This loss ratio ( LR ) can be simplified to

$$LR = (V / I) \left[ \frac{4}{X_c} + \frac{\sin(a)}{2} * X_L \right] \qquad (9\text{-}8)$$

Thus , the loss ratio may be clarified as a list of ratios to give the performance of this loss in any network and so, the ratios are listed in Table 9-2 with their maximum ranges which would be investigated now .

Table 9-2 : The ranges of maximum ratios

| Ratio | Equivalent Expression | Range of Variation |
|---|---|---|
| $Z_{in}$ | V / I | Constant |
| M | $X_c / X_L$ | 0.6 - 2.0 |
| N | $X_L / R$ | 10 - 16 |
| a | control angle | 1 - 8 |

The final expression, under the consideration of constant ratio between voltage and current at the sending end ( input impedance), for the loss ratio will be :

$$LR = \frac{Z_{in}}{X_L} \left[ \frac{4}{M} + \frac{\sin(a)}{2} \right] \quad , \quad \{2, (1 + N)\} \qquad (9\text{-}9)$$

The required term in this equation will be specified as the loss term (K) in the range 2 – (N+1) as:

$$K = \frac{4}{M} + \frac{\sin(a)}{2} \qquad (9\text{-}10)$$

This loss term is tested for the regions with respect to the first coefficient N.
The passive loss in a system depends on the assumed parameters where its values are highly decreased with the increase of parameter (N) . This means that the presence of high ratio of inductance to the resistance of a line will decrease the loss but this result induced to open the effect of the M factor where the results were illustrating no effect practically on the loss term . Consequently, the last factor of the control angle should be tested to prove the real role of the control angle.
Both upper and lower extremes as a function of the set {M,N) as it varies from { 0.6 , 10 } to a minimum at {2,16}. The line curves denote the case of M = 0.6 while the dashed means the value of 2. It pointed a great effect and a high increase in the loss with the increase in the control angle so that a small value should be controlled for the reduction of loss in any network.

## II - LOSS UTILIZATION

However, distribution networks take a small role in this field and consequently the concentration for more detail study of some items in them may be analyzed. The energy management appears to be one of the vital problems that cover the use of energy in them. The energy loss in the distribution systems can be classified into 3 groups as social, technical and grammar use losses. The companies of electric distribution cover the problem of technical loss in distribution systems while they treat the social losses in the network in spite of its importance for the economic point of view .
The most important loss can be called as " GRAMMARLESS LOSS " ( GL) where companies and even the consumers ignore it at all. This loss is now without control from either company or consumer. The problem of fuel in the world is forcing us now to take ( GL ) into consideration for minimization of the fuel consumption .
The effect of bad connections on energy has been given in while it is now required to be under control. Different types of these connections may be included and each item illustrate the atmosphere of suitable control. Also, the lighting loads in houses consumes a lot of energy that needs a good improving for the use of light as a whole and then it can be said that lighting and heating loads will have a considerable values.

## III - LOSS MANAGEMENT

The electrical connections are classified into two main types as connected or isolated where the important connected terminals are then tailored into two major parts as called as permanent ( good ) and temporary (bad) connections. The permanent connection is a good one while its quality depends on the characteristics of loading either normal or overloaded. The overloaded connections lead to an overheating effect at the spot reaching the melting of the metal connectors and consequently the damage of the insulation holding this connection besides the external pollution .

The temporary connections (bad) are tailored into 4 different types such as loose, vibrated , overloaded and sparking connections where the last generates both overheat and ionization leading to static charges with their negative hurting effect. The insulation can be damaged quickly since its life period will be reduced due to bad operations. This indicates that a fundamental program for the training must be one of the vital subjects in the modern operation of united networks. The maintenance programs will be helpful with a good training. So , a routine maintenance of GL is important to save energy on our earth.

This means that a good management for energy loss alone specially that called GL will be very necessary. This proves a need for the creation of a special management department which may be divided into three major sectors for the conservation of energy as well as to prevent the loss in energy due to GL where each sector is directed towards a step of operation. Also, it may be mentioned that only transistor devices as TV , radio, etc. should be used while all lamp devices must be switched off to be out of operation .

These four sectors are defined as installation, operation, check quality and finally maintenance sectors to minimize GL. The quality control in industry either for electrical connections or for the used device and machines as utilities at the user ends is a sector. It may review the operation of such an equipment with different actual applications to check the performance and the suitability for use. This can be controlled through 3 sections as testing certificates before use and guarantee cards as well as the final step of operation test as a minimum level for the instruction of use including the catalogues. The operation sector is directly related to installation before operation check and the maintenance after operation. The maintenance may be a routine one while capital maintenance means the replacement of damaged parts .

Finally, from these items it can be concluded, for the design consideration, that:

1 - The grammarless loss must be eliminated from power networks.

2 - The proposed active management for GL should be implemented an all networks through training and routine maintenance .

3 - TV programs for learning, explaining and training of GL will help well in energy conservation .

4 - Devices must be checked by a special sector before use .

5- The control angle between bus voltages can reduce the loss.

# 9-8: ECONOMIC PRICEING FOR ENERGY CONSUMPTION

Nowadays, the fuel consumption is floating on the surface of the most important problems in the world so that all efforts may be directed towards the saving of the traditional energy sources, which appear to be the simple used fuel. The renewable energy is hardly introduced to the field of energy source to be utilized, either besides or instead of the traditional types of fuel.

The traditional energy produces a lot of substances that pollute the environments surrounding our life. Although the spread utilization of such item, a new type of energy generation would be needed to replace the polluted area by another clean one. However, the utilization of energy sources must be an economic problem to decide its use where the traditional fuel is still the most economic one. In spite of this condition the solar energy may be useful in far places and in shiny zones and where the required loads are small and far from the country network. This is a plus advantage for the use of solar energy.

## I - ECONOMIC TARIFF

Today, some of the big national projects has been born tending to help the industry and commercial situation of Egypt such as TOSHKI in the south of the land in order to higher the possibility of mutual connection with others in the field of exporting including the special sector besides the governmental one. It should be noted that the change from the unique directed economy to another opened depending on both individual and investment sectors either the local or the foreign capital for reforming the overall economy to form a good and strong base is required.

In this concern we find that the consumption energy is the vital subject for the reforming policy especially the routine energy either the consumed or the lost through the concept of management or the pricing or even in the cost of the instruments and devices. This normally, takes more value with the electricity sector.

This presents that the installed power can't be used totally over all the time where the economic tariff as the price of energy unit for a given country may be defined as :

$$\text{Tariff} = \frac{\text{total cost}}{\text{total actual consumption}} \qquad (9\text{-}11)$$

## II - TOTAL COST

The total cost means the total spent money for the given consumption at the end of consumers . This would be illustrated in a simple form where a complete covering for the items of a network up to the service of popular as spread on the Earth . Now, the value of the electric consumption has been continuously increased on either the individual or the national levels so that the way to share in the capital assets may be the suitable. This leads the capital stock to higher step of economy instead the lazy position of the available capital of individuals

though companies or banks. The social behavior should be varied with the appeared new shape of economy taking the consuming activities to be replaced by the production type and its relatives through the marketing and auxiliaries. This strategy will help in raising the investment consumption level through the reforming of used energy in different ways of electricity, water, sewage, cleaning communications and transportation. In this concern the actual consumption of the above equation is known as :

$$\text{consumption} = \text{total installed energy} - \text{unused energy} - \text{dead energy} \quad (9\text{-}12)$$

If we return to Equation 9-11, the term of dead energy appeared in Equation 9-12 will be a vital amount specially with large values of spare power. However, the dead energy depends on the planning procedure that may fail sometimes according to the sudden variations in the social or political of a country so that this will be more suitable if its value is minimized as possible as it can.

Recently the actual saving in this item can be realized as the Arab Countries go to the policy of mutual connection between the own national networks and consequently the spare energy for each one can be really disappeared due to the spare of the overall connected general network. This will decrease the total cost in equation 9-11 and should reduce the tariff of the energy. Also, the dynamometer can be increased through some technical aspects as illustrated below.

## III - LOSS COST

The required concept to cover the suggested problem can be appeared in the coding process utilized for the implementation of the consumed energy. In other words, it is needed to managing the problem of utilization of energy. This means that we must control the energy consumption in the network either though generation or transmission or even distribution systems. Otherwise, minimizing the fuel loss is still the main aim for the generation process as a whole while the electric loss in the generation step appears to be within the acceptable region.

Each sector has its own character from the point of view of energy loss . The first part losses its energy in both the normal technical electrical loss besides energy loss which is clear in the heat loss . Otherwise the heat loss is the most important factor in the problem of conservation of the energy. It may be expressed in terms of the fuel that used in the burning process. So, it is dependent on the fuel characteristic as well as the fuel burning efficiency where the new tendency goes to implementing co-generation or combined cycles systems.

The second stage in a network is the transmission where a new factor would be appeared to decrease the utilization of input energy. This new factor will be the induced reactive power in the transmission system due to the self parameters of the system. In this sector the reactors must be installed at the terminals of long EHV and UHV lines to develop their performance. Also, the synchronous condensers would be required to compensate reactive power in order to decrease the raising of voltage. These condensers may improve the power factor

in the transmission system leading to minimizing the power active loss in the sector. Actually such concepts are used in the 500 kV system of Egypt.
The third section is the distribution system where the problems of both transmission and the fourth section (utilization) will be reflected on its performance so that the reactive power troubles may be one of the important parameters of loss. Otherwise the electrical active loss can be the nominal one that can't be modified. The other part of loss is the social loss which includes the different types of consumers. Some of them may try to take energy or some without counting. Others have damaged electric counters while a little of them can't pay for energy for commercial reasons. All these problems can be solved by good maintenance and management . It is known that the item of loss is one of the 5 branches of cost. The cost of unused energy must be treated through the planning but the cost of network loss can be tailored different types of loss in the network. Although the transmission loss is minimized in this part of the network, the loss in the reactive power appears to be the main goal. This is leading to the importance of the improvement of power factor in the transmission systems. However, the distribution network takes a small importance in this field and consequently the concentration for the details of some items in the distribution system may be required to be analyzed. The energy management is one of the vital problems that may cover its use.
Energy loss in the distribution systems can be classified into three groups such as social, technical and grammar use losses. The companies of electric distribution cover technical loss while they may not treat completely the problem of social losses in spite of its importance from the economic point of view .
The terms of this final Equations may be explained in a general form where the nominal loss is equivalent to the technical loss that must be presented in a circuit as active loss which cannot be avoided at all. On the other hand, the second term expresses that loss due to the uncontrolled behaviors of some persons such as the different occasions of society either individual or grouping type or even the national one.

## IV - POWER FACTOR IMPROVEMENT

The last term of Equation above (9-12) means the loss due to the utilization process and it is related to the presentation of reactive power in the network leading to the technical loss but of that type which it can be controlled on the bases of technical treatment for the electrical circuit. This reactive power may be appeared with the use of some gas lighting lamps of the low p. f. character which reaches 0.4 in most cases of applications specially with a large number of small spread amounts as well as the utilization of motors in many steps of home or workshop needs .
For such problems the power factor modifiers must be implemented as condenser and synchronous machines and so the reactive power can be reduced increasing the excess of actual active power for the same value of generated power. This is a very important view where this will help directly in the given above dead energy to increase the spare power for the same generation and finally the decrease in the total cost of Equation 1 can be defined by n % of the initial value of cost . The increase of the utilized energy due to the power factor improvement would be m % of the initial consumption, and therefore, the save in the tariff can be expressed mathematically.
From this given above analysis, it is concluded that :

1 - Tariff reduction can be easily reached through reforming of energy consumption and power factor modification.
2 - The connection between all national networks of the Arab Nations will help in decreasing the tariff.
3 - The dead energy must be minimized as possible to reduce the tariff of energy as a whole.

## 9-9 : A CORRELATION FOR ENERGY COST

The energy costing is a known type of Engineering problems in all countries due to the modification every day in the style of equipment for control or even in protection schemes. Thus, it has been studied in details and the characteristics of tariff are defined well. On the other hand, the new types of stations and the performance of optimal power flow in electric networks may direct the problem of costing for the consumed energy to include the varied shape of load curves. This transforms the research to a created zone for applications such as the presented paper,

Table 9-3: The basic tariff for the domestic sector in Egypt

| Energy | 100 | 200 | 300 | 400 | 500 | 1000 | 2000 | 3000 | 4000 |
|---|---|---|---|---|---|---|---|---|---|
| Tariff base | 180 | 480 | 860 | 1280 | 1740 | 5290 | 15290 | 27290 | 39290 |
| $P_{av}$ (/ kWh) | 1.8 | 2.4 | 2.86 | 3.2 | 3.48 | 5.29 | 7.645 | 9.096 | 9.82 |
| RRP (base) | 1 | 1.33 | 1.58 | 1.77 | 1.93 | 2.93 | 4.24 | 5.05 | 5.69 |
| RRP (stripe) | 1 | 1.33 | 1.19 | 1.11 | 1.08 | 1.52 | 1.44 | 1.18 | 1.07 |

However, the price of energy must be updated according to the modification in the system. The tariff of electric energy in Egypt (as an example) is considered for the technology of evaluation . The principle of tariff for energy consumption has been widely investigated for a long time, consequently, this tariff in Egypt is based on the striped style as listed in Tables 9-3 and 9-4. Table 9-3 related to the domestic loads while Table 9-4 gives the tariff for the commercial sector including the industrial loads The rate of rise of price (RRP) for each stripe is accounted for two conditions (relative to base and with respect to the stripe itself). Its value is growing with the consumed energy in the case of base evaluation in the two sectors.

Table 9-4 : The basic tariff for the commercial (industrial) sector in Egypt

| Energy | 100 | 200 | 300 | 400 | 500 | 1000 | 2000 | 3000 | 4000 |
|---|---|---|---|---|---|---|---|---|---|
| Tariff base | 210 | 570 | 1210 | 1970 | 2850 | 7850 | 19850 | 33850 | 46850 |
| $P_{av}$ (/ kWh) | 2.1 | 2.85 | 4.03 | 4.925 | 5.7 | 7.85 | 9.925 | 11.28 | 1.96 |
| RRP (base) | 1 | 1.35 | 1.91 | 2.34 | 2.71 | 3.73 | 4.72 | 5.37 | 5.69 |
| RRP (stripe) | 1 | 1.35 | 1.41 | 1.22 | 1.15 | 1.37 | 1.26 | 1.13 | 1.06 |

Since the present section related to a high mathematics, the used signs and symbols are listed in Table 9-5.

## I- Energy Price

**The pricing of energy depends on two sections of cost as given by:**

$$\text{Total Cost} = \text{Fixed Cost} + \text{Running Cost} \qquad (9\text{-}13)$$

**This equation means that the costing of energy must depend on, firstly, the capital cost of stations (Power Stations, Substations) and the connection between them with the ends of utilization. Secondly, the cost depends also on the running cost, which means the consumed power where the presented research is concentrated to solve the problem of evaluation for both sides (*customers and Electricity Company*). This is more important in some countries as it will be concluded later so that a modification for the process of costing may be needed and therefore, the problem could be correlated.**

**The fixed cost will be omitted out of the study in order to concentrate the analysis on the energy only. The process of determination of the tariff contains the average price of the energy, which can be specified to each sector to cover all possible variations in the loads of customers in the deduced shape of the stripes in KWH. The average monthly price $P_{av}$ in the units of L. E. for the total energy ($E_t$) may be formulated as a function of the total energy used in the units (KWh) by:**

$$P_{av} = (1/(E_t)) \times \sum_{i=1}^{n_c} (P_i \times KWh_i) \qquad (9\text{-}14)$$

**Table 9-5 :** ***Nomenclature***

| symbol | title | symbol | title |
|---|---|---|---|
| L. E. | Egyptian pound | $P_m$ | price of average in the strip m $^{th}$ |
| $n_c$ | number of customers in the distribution network | $KWh_i$ | energy reading for the $i^{th}$ month |
| RRP | rate of rise of price | $P_i$ | price of energy for the i $^{th}$ month |
| P. T. | Egyptian coin (100 P. T. = L. E.) | $E_t$ | total energy consumed |
| $E_1$ 1, $E_2$ & $E_3$ | overall value of energy in the $1^{st}$, $2^{nd}$ & $3^{rd}$ stripe, respectively | $P_{av}$ | monthly average price |
| $e_2$ | value of energy inside the $2^{nd}$ stripe and less than $E_2$ | $P_i$ | instant recorded reading for the i $^{th}$ month |
| $e_3$ | value of energy inside the $3^{rd}$ stripe and less than $E_3$ | $P_{i-1}$ | recorded reading for the i $^{th}$ month |
| T | month time (period) | $t_i$ | time increase in i $^{th}$ month |
| $T_i$ | The period of i $^{th}$ month | $R_i$ | energy reading for i $t^{th}$ month |
| X | mean value of the population measurements | $\mu$ | mean value of the samples |
| $X_i$ | reading at the i $^{th}$ month or day or hour | f | frequency of readings |
| $X_w$ | weight load mean | $X_g$ | grouped mean |
| F | cumulative frequency for the class before the middle class | M | midpoint point of each class (group ) |
| $L_{md}$ | lower boundary of the middle class | $f_{md}$ | frequency of the middle class |
| C | class interval of median class | $D_a$ | difference between frequency modal and before one |
| $D_b$ | difference between frequency of middle class and the next | P | Pearson lan coefficient of skew ness |
| N | number of population | n | number of samples ( $n < N$ ). |
| S | standard deviation for the population | $\sigma$ | standard deviation for the samples |
| $W_i$ | weight of reading of the i $^{th}$ month or day or hour | $\alpha$ | Correlation factor for energy consumption |
| $\beta$ | Correlation factor for load curve (unused energy) | | |

**This average price should be equivalent to that deduced according to the stripes of the customers where they have m classes for each sector and the price in each can**

**be remarked as $P_m$ for the m th stripe ( It varies between 1 and 9 as indicated in Tables 9-3 and 9-4). Then, the average price will obey the same given expression in eq. (9-14). The developed static and dynamic values for the tariff of both mentioned sectors above are calculated and listed in Tables 9-6 and 9-7. All values are based on the P. T. units.**

**Table 9-6: The deduced energy price (in P. T.) for the domestic sector in Egypt**

| Energy from to (kWh) | 0-100 | 100-200 | 200-300 | 300-400 | 400-500 | 500-1000 | 1000-2000 | 2000-3000 | 3000-4000 |
|---|---|---|---|---|---|---|---|---|---|
| Energy cost | 180 | 300 | 380 | 420 | 460 | 3550 | 10000 | 12000 | 12000 |
| Energy price | 1.8 | 3 | 3.8 | 4.2 | 4.6 | 35.5 | 100 | 120 | 120 |
| RRP (base) | 1 | 1.66 | 2.11 | 2.33 | 2.55 | 19.72 | 55.55 | 66.66 | 66.66 |
| RRP (dynamic) | 1 | 1.66 | 1.26 | 1.11 | 1.09 | 7.71 | 2.81 | 1.2 | 1 |

**Table 9-7: The deduced energy price (in P. T.) for the commercial sector in Egypt**

| Energy from To (kWh) | 0-100 | 100-200 | 200-300 | 300-400 | 400-500 | 500-1000 | 1000-2000 | 2000-3000 | 3000-4000 |
|---|---|---|---|---|---|---|---|---|---|
| Energy cost | 210 | 360 | 640 | 760 | 880 | 5000 | 12000 | 14000 | 14000 |
| Energy price | 2.1 | 3.6 | 6.4 | 7.6 | 8.8 | 50 | 120 | 140 | 140 |
| RRP (base) | 1 | 1.71 | 3.04 | 3.61 | 4.19 | 23.81 | 57.14 | 66.66 | 66.66 |
| RRP (dynamic) | 1 | 1.71 | 1.77 | 1.18 | 1.15 | 5.68 | 2.4 | 1.66 | 1 |

**It is remarked that RRP for the base conditions is highly increased with respect to the initial cases of Tables 9-3 & 9-4. However, the dynamic values were vibrated between 1 to 5.68 (instead of 1 to 1.37) for industrial loads and 1 to 2.81 (instead of 1 to 1.52) for the domestic. This means that the system of accounting is directed to protect the small customers. Hence, the computed cost difference between the dynamic and static tariff for the domestic and industrial loads is given in Table 9-8. The appeared rate of increase in the cost is usually changed not only between stripes but also inside each stripe itself.**

**Table 9-8: The calculated cost difference between dynamic / static tariff**

| Energy | For domestic loads | | | | For commercial loads | | | |
|---|---|---|---|---|---|---|---|---|
| (kWh) | Pitch (P. T.) | Energy cost / average | Cost / strip | Rate of increase | Pitch (P. T.) | Energy cost / average | Cost / strip | Rate of increase |
| 100 | 75 | 180 | 180 | 0 | 90 | 210 | 210 | 0 |
| 125 | | 300 | 255 | 45 | | 356.25 | 300 | 56.2 |
| 150 | | 360 | 330 | 30 | | 427.5 | 390 | 37.5 |
| 175 | | 420 | 405 | 15 | | 498.75 | 480 | 18.7 |
| 200 | | 480 | 480 | 0 | | 570 | 570 | 0 |
| 225 | 95 | 643.5 | 575 | 68.5 | 160 | 906.75 | 730 | 176.7 |
| 250 | | 715 | 670 | 45 | | 1007.5 | 890 | 117.5 |
| 275 | | 786.5 | 765 | 21.5 | | 1108.25 | 1050 | 58.2 |
| 300 | | 860 | 860 | 0 | | 1210 | 1210 | 0 |
| 325 | 105 | 1040 | 965 | 75 | 190 | 1600.62 | 1400 | 200.6 |
| 350 | | 1120 | 1070 | 50 | | 1723.75 | 1590 | 133.7 |
| 375 | | 1200 | 1175 | 25 | | 1846.87 | 1780 | 66.8 |
| 400 | | 1280 | 1280 | 0 | | 1970 | 1970 | 0 |
| 425 | 115 | 1479 | 1395 | 84 | 220 | 2422.5 | 2190 | 232.5 |
| 450 | | 1566 | 1510 | 56 | | 2565 | 2410 | 155 |
| 475 | | 1653 | 1625 | 28 | | 2707.5 | 2630 | 77.5 |
| 500 | | 1740 | 1740 | 0 | | 2850 | 2850 | 0 |
| 600 | 355 | 3174 | 2095 | 1079 | 500 | 4710 | 3350 | 1360 |
| 700 | | 3703 | 2450 | 1253 | | 5495 | 3850 | 1645 |
| 800 | | 4232 | 2805 | 1427 | | 6280 | 4350 | 1930 |
| 900 | | 4761 | 3160 | 1601 | | 7065 | 4850 | 2215 |
| 1000 | | 5290 | 5290 | 0 | | 7850 | 7850 | 0 |

## II- Energy Consumption

**Since the stripe price inside the total consumption depends on the actual period for the measurement, the applied date for the recording the consumed energy must be the same each month, i. e. a constant cycle of time (T). This process is very difficult due to the manual system for recording so that a deflection may be occurred in the determined consumed energy. The recorded reading $P_i$ in a month x as due to the difference between instant reading $R_i$ and last before $R_{i-1}$ will be expressed mathematically by:**

$$P_i = R_i - R_{i-1} \quad (9\text{-}15)$$

**This may be tailored for the first month as:**

$$P_1 = E_1 + E_2 + e_3 \quad (9\text{-}16)$$

**The incorrect reading will be deduced if the next month (second) reading takes the form:**

$$P_2 = E_1 + e_2 \quad (9\text{-}17)$$

**Where $e_2$ is the value of energy in inside the level of this stripe where its value is less than $E_2$.**

**If $e_2 + e_3 < E_2$, a vital mistake will be illuminated on the surface in the estimated total cost of the consumed energy. Whatever, this cost does not touch the principle of tariff at all, and so, a correlation factor may be needed.**

## III- CORRELATION FACTOR FOR ACCOUNTING

**It is well known that the load curve for a specified place cannot be the same every day due to the performance of its variation, and so, the speech about all populations of loads may be impracticable. Hence the concept of simulation (sampling) may be the way to investigate the overall characteristics of a load. However, it will be a step in the way to cost the energy consumption in the network. The sample must reflect the over all view of consumers in the studied field since it may be for only one sector of customers. Two directions for the variation in a random way are needed. The first is the change in the number of customers connected at the ends of the distribution network while the second will be the continuous addition for due to consumers or all together.**

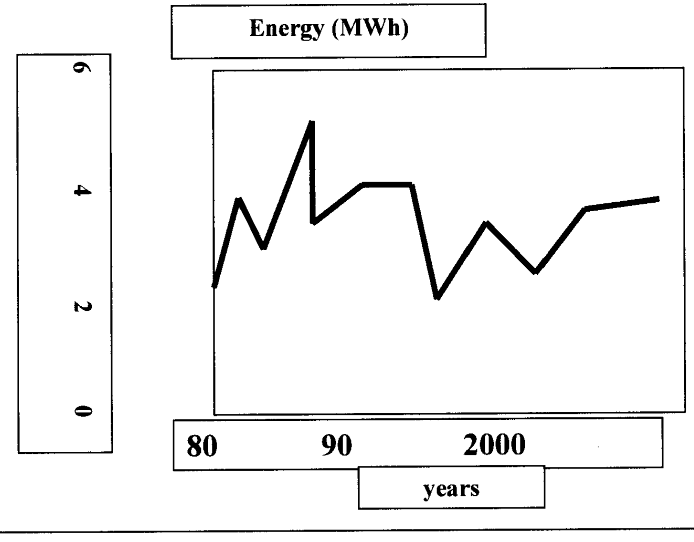



Fig 9-3: A sample of end user

**There are two axes for the possible mistake in the process of accounting to find the total cost for the consumed energy in a certain reading or the sequence of measurements. The treated, here, such mistake may be appeared in either the time period or the stripe zone. This can be illustrated in the following paragraph.**
**A sample of readings is registered for a time range of 20 years as given in Fig. 9-3 for the yearly energy consumption with an oscillated character.**

**Table 9-9: The Results of the studied sample**

| Till | Consumption( kWh) | Total cost (L. E.) | Average price (L. E./kWh) | Price grow ratio | Price to last year ratio |
|---|---|---|---|---|---|
| 1981 | 2111 | 34.125 | 1.6165 | 1 | 1 |
| 1982 | 5665 | 99.552 | 1.7573 | 1.0845 | 1.0845 |
| 1983 | 7963 | 144.382 | 1.8131 | 1.1216 | 1.0342 |
| 1984 | 11948 | 230.932 | 1.9328 | 1.1956 | 1.0659 |
| 1985 | 16467 | 359.217 | 2.1814 | 1.3494 | 1.1286 |
| 1986 | 19316 | 436.592 | 2.2602 | 1.3982 | 1.0361 |
| 1987 | 22644 | 530.462 | 2.3426 | 1.4491 | 1.0364 |
| 1988 | 26029 | 626.692 | 2.4076 | 1.4894 | 1.0278 |
| 1989 | 29542 | 745.597 | 2.5238 | 1.5612 | 1.0482 |
| 1990 | 31376 | 793.012 | 2.5274 | 1.5635 | 1.0014 |
| 1991 | 33653 | 872.292 | 2.592 | 1.6034 | 1.0255 |
| 992 | 36862 | 1049.382 | 2.8467 | 1.761 | 1.0983 |
| 1993 | 39634 | 1242.707 | 3.1354 | 1.9396 | 1.1014 |
| 1994 | 41597 | 1444.302 | 3.4721 | 2.1479 | 1.1073 |
| 1995 | 44696 | 1715.172 | 3.8374 | 2.3738 | 1.1052 |
| 1996 | 48023 | 1999.782 | 4.1642 | 2.576 | 1.1085 |
| 1999 | 56200 | 337102.88 | 5.998 | 3.7104 | |

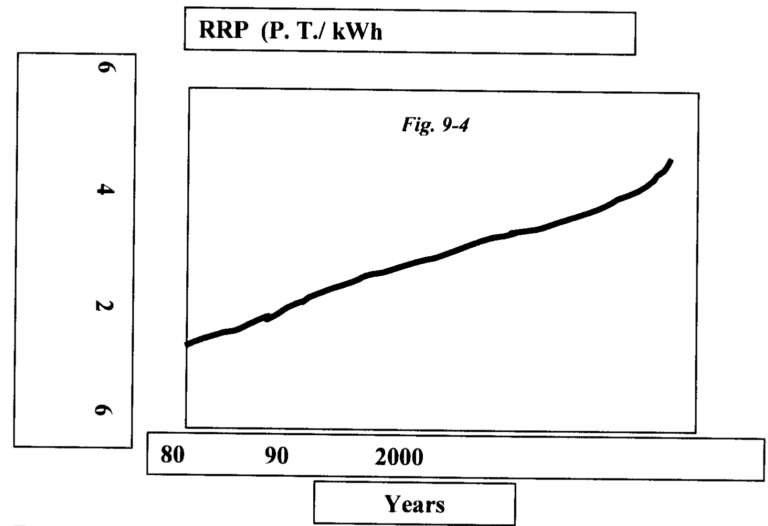



*Fig. 9-4*

The given values (Table 9-9) are true without any deviation on the bases of the presented tariff of energy in Egypt. The RRP for the energy consumption is presented also in Fig. 9-4 in (P. T. / KWh) where it is seen in raising shape as in Fig . 9-5.

The deduced items affecting the studied correlation for energy cost will be listed in the Table 9-8 according to the tariff base of Tables 9-3 and 9-4. The axes of deflection will be induced as in the period $T_i$ for a sequence of readings ($R_i$) with their energy ($P_i$) as a function of the exact month time T (usually T= 30 days). An excess time $t_i$ may control the required aim where the index i means the 12 months ($i = 1, 2, \ldots, \ldots, 12$). Then, the reading of energy for the month could be expressed as:

$$R_i = T + t_i \qquad (9\text{-}18)$$

The annual average energy can be expressed as the sum of monthly readings within the year divided by the number of months in spite of the number of readings may be different. This case represents the first axis of mistake that needs a correlation as proved by the extracted points of mistake (See Table 9-9).

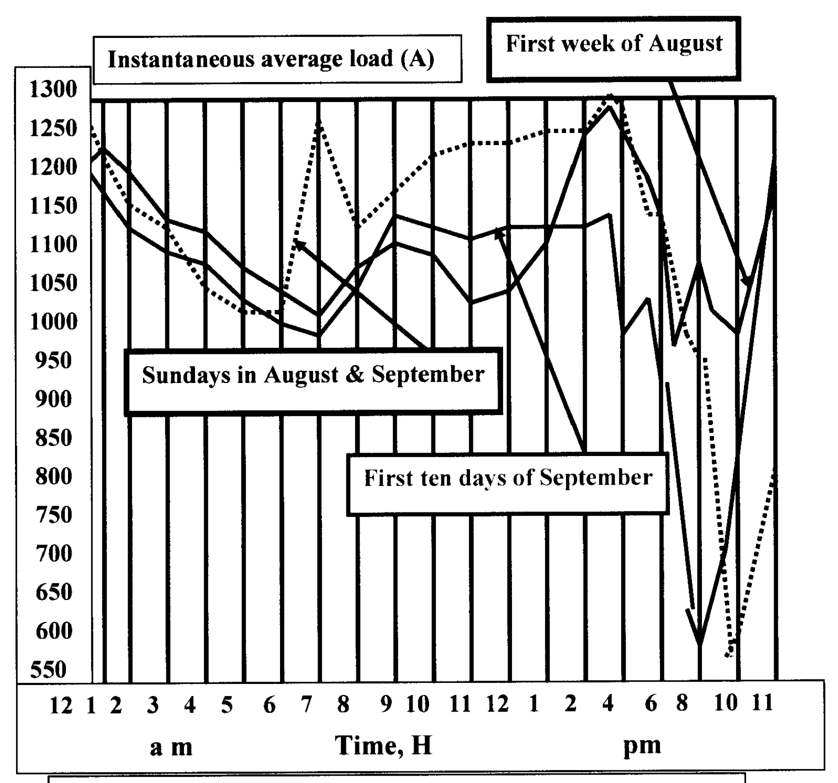



**Fig. 9-5: The variation of instantaneous average load**

**Thus, the second axis will be as given by equations 9-17 related to the time of the consumed energy in different periods leading to a mistake in the suitable stripe of the tariff. The selected readings in the studied example are presented in the Table 9-10 in order to illustrate the objective of the work. Whatever, the places of such mistake in the accounting process are shown in the raw numbers 1, 2, 3, 13, 14, and 16. These readings lead to an apparent cost which will be correlated.**

**The correlation factor for the first item may be the division to get the average monthly reading and then another one to correlate the period, but only one factor ($\alpha$) can proposed to cover both mistakes in the form:**

$$\alpha = 1 + (t_i / T) \quad (9\text{-}19)$$

**Table 9-10: The selected readings for comparison**

| Date month / year | KWh/month reading | Energy cost | Energy (KWh) /month | Cost/month | Equivalent value (Average/ dynamic) | Average ratio | dynamic ratio |
|---|---|---|---|---|---|---|---|
| 10/80 | 127/2 | 2.163 | 63.5 | 1.08 | 1.14 | 0.948 | 0.948 |
| 4/81 | 349/3 | 5.83 | 116.3 | 1.16 | 2.79 - 2.19 | 0.415 | 0.529 |
| 7/82 | 1497/5 | 27.42 | 300 | 5.48 | 8.6 | 0.637 | 0.637 |
| 2/83 | 300/1 | 5.55 | 160 | 5.55 | 8.6 | 0.645 | 0.645 |
| 10/84 | 160/1 | 3.065 | 301 | 3.06 | 3.84 - 3.66 | 0.798 | 0.837 |
| 9/85 | 301/1 | 8.385 | 151 | 8.38 | 8.6 | 0.975 | 0.975 |
| 9/86 | 151/1 | 3.325 | 300 | 3.32 | 3.6 - 3.32 | 0.923 | 1 |
| 7/87 | 300/1 | 8.6 | 300 | 8.6 | 8.6 | 1 | 1 |
| 5/88 | 300/1 | 8.6 | 250 | 8.6 | 8.6 | 1 | 1 |
| 12/89 | 250/1 | 5.4 | 124 | 5.4 | 7.15 - 6.7 | 0.755 | 0.805 |
| 7/90 | 124/1 | 3.04 | 102 | 3.04 | 2.97 - 2.5 | 1.02 | 1.216 |
| 8/91 | 102/1 | 3.09 | 524.5 | 3.0 | 2.44 – 2 | 1.266 | 1.658 |
| 5/92 | 1049/2 | 61.9 | 318.5 | 30.95 | 27.74- 18.66 | 1.115 | 1.54 |
| 3/93 | 637/2 | 42.46 | 195 | 21.23 | 10.19 $^{3}$ 9.17 | 2.08 | 2.31 |
| 6/94 | 195/1 | 14.54 | 425 | 14.54 | 4.68 $^{3}$ 4.08 | 3.106 | 3.56 |
| 4/95 | 2125/5 | 213.5 | 377 | 42.7 | 14.79 $^{3}$ 13.95 | 2.887 | 3.06 |
| 4/96 | 377/1 | 35.5 | 187 | 35.5 | 12.06 $^{3}$ 11.06 | 2. 94 | 3.209 |
| 2/97 | 187/1 | 13.88 | | 13.88 | 4.48 - 3.88 | 3.098 | 3.577 |

## IV - Statistical Measurements

**Since the load is continuously varied, the consumed energy will not be a constant at all times. So, a new correlation factor may be required to adjust the performance of tariff as well as to bring the economic pricing in the right margin. Also, this process appears to be a direct reflection for the statistical type of variation, and consequently, it may be taken according to the load curves of the network either in the end locations or in the city as a whole. The case of end users is analyzed above while the next part of work considered the load curves in Port Said City as an example for the idea of correlation. This leads to the importance of statistical parameters to cover the probable values during the period of study. The fundamental factors may be essential to represent all readings as they are tailored into the following items.**

$$X = [\Sigma X_i ] / N , (i=1,\ldots,N) \qquad (9\text{-}20)$$

### 1- Average Load

**All values of a subject in general cannot represent a problem so that only one value may summaries all of them. Consequently, the input data for the load curves are summarized as a Population Mean which may be taken as a mean value or in the field of electricity as the average load X in the form:**

**Table 9-11: Daily average load for the 1st week of August 1999 (in A)**

| **Day** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| **Average** | **1035** | **1215** | **1090.8** | **1131.6** | **1242.5** | **1066.6** | **900** |

**The average value of a load curve is the same as the mean for the statistical studies but here this average is tailored in different ways such as the *Instantaneous Mean***

as given in Tables 9-11 , 9-12 and 9-13 for the three different cases inside the same overall readings of the load curves in Port Said City.

Table 9-12: Daily average load for September 1999

| Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | 1035 | 1039.1 | 1079.1 | 952.1 | 976.6 | 1213.3 | 714.1 |
| Day | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Average | 1160.4 | 1045 | 855 | 904.1 | 1055.8 | 1192.5 | 1039.1 |
| Day | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| Average | 1025.8 | 755.8 | 942.1 | 1047.5 | 1270.8 | 1251.2 | 975 |
| Day | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Average | 1227.5 | 1245 | 1093.3 | 1210.8 | 1143.3 | 1175.8 | 1133.3 |

**Whatever, the daily average load can be computed for all instantaneous values as a statistical base of mathematics as listed in Table 9-11 for the first seven days of August inside the analyzed data. It is remarked some difference between results in above Tables and the next due to the automatic change in the consumed load.**

**Table 9-13: Daily average load for some cases ( units in A )**

| Case | Concept | Daily Average load | N |
|---|---|---|---|
| Days 1 , 20 , 23 /9 | Random | 1126.6 | 72 |
| Days 1 , 7 ,25 /8 | Random | 1124.7 | 72 |
| Days 3 , 17 , 26 /8 | Random | 1063.03 | 72 |
| Sept. | Sundays | 981.98 | 120 |

**The calculations for the other cases are given in Table 9-12 for September with the above remarks in deduced daily average loads. However, Table 9-13 lists the random collections of readings to prove that the value of mean load cannot express the actual view for the collections of data. This means that one or more factors may be needed. Since the single average value is absent, another one factor or more will be required to complete the view about measurements.**

## 2- Dispersion Factors

**This parameter expresses the shape of dispersion of the data around the mean value and it gives correctly their distribution along the studied period. So, another important factor besides the mean value must be accounted as the variance ($S^2$), which gives the known important parameter as the standard deviation (S) according to the formula:**

$$S = \sqrt{\Sigma[X_i - X]^2 / N} \quad , (i=1,\ldots,N) \qquad (9\text{-}21)$$

**This standard deviation (S) for the population measurements will be expressed for the sampling method on (n) samples as ($\sigma$) in the form:**

$$\sigma = \sqrt{\Sigma\ [X_i\ -\ \mu]^2/(n-1)}\ ,\ (i=1,...,n) \qquad (9\text{-}22)$$

**The evaluated dispersion factor (standard deviation) for the studied data is given data in Table 9-14 for the load curves in September 1999.**

***Table 9-14: Standard deviations of readings***

| Case | Time | Average | N | S | σ | σ/ S |
|---|---|---|---|---|---|---|
| 1-10 September | Midnight | 1236 | 10 | 31.61 | 35.12 | 1.11 |
| 1-7 August | Peak | 1282.85 | 7 | 36.46 | 42.53 | 1.16 |
| 1-7 August | Light load | 975.14 | 7 | 191.34 | 223.23 | 1.16 |
| 1/8/99 | 24 h | 1035 | 24 | 64.35 | 67.14 | 1.04 |

**The results show that the case of given data has a different value for the sampling process as a ratio (σ/ S) in the last column of the Table. This proves that more readings for the sample will be necessary to give accurate results.**

## 3- Grouped Data

**On the other hand, data may be scattered in a wide range and then the system of grouping will be the best concept for the evaluation process. This principle appears when the computation of Weekly Mean, as a *Grouped Mean ($X_g$)*, which formulated as:**

$$X_g\ =\ [\Sigma\, f\ M\ ]\ /\ n = [\Sigma\, f\ M\ ]\ /\Sigma\, f \qquad (9\text{-}23)$$

**This type of computations may be needed, too, for the determination of annual average load or even the monthly value. ......also, a median will be necessary for the results in the form:**

$$\text{Median} = L_{md}\ + C\ [\ n/2 - F\ ]\ /\ f_{md} \qquad (9\text{-}24)$$

**The group mode as one of the most important parameter for the grouped data would be necessary in order to determine the general form of data distribution where it is formulated as:**

$$\text{Group Mode} = L_{md} + C\ D_a\ /[D_b\ + D_a] \qquad (9\text{-}25)$$

**The standard deviation in this case is deduced according to the mathematical formula:**

$$S = \sqrt{\Sigma[f M^2 - n X^2]/(n-1)} \quad (9\text{-}26)$$

**Table 9-15: The calculated factors for the specified cases**

| Case | Case (a): The first week of August | Case (b): Sundays (September and August) | Case ( c ): Individual month of September |
|---|---|---|---|
| Readings n | 168 | 216 | 696 |
| Average | 1102.64 | 1072.83 | 1072.77 |
| Mode | 679.05 | 613.95 | 605.96 |
| Median | 1583.5 | 1952.3 | 645.33 |
| Standard deviation | 224.7 | 922.95 | 346 |
| Skew ness Factor (P) | - 6.42 | - 1.569 | 3.706 |

**Consequently, the cumulative frequency can be accounted for the different cases of readings (Table 9-15) where their classes are determined in Table 9-16.**

**Table 9-16: The margin of different cases**

| Case | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 | Class 6 | Class 7 |
|---|---|---|---|---|---|---|---|
| (a) | 21-220 | 221-420 | 421-620 | 621-820 | 821-1020 | 1-21-1220 | 1221-1420 |
| (b) & (c) | 0-299 | 300-599 | 600-899 | 900-1199 | 1120-1499 | - | - |

**These cases are denoted for the following Tables and Figures. The shown factor of skew is required to understand the shape of data along the distribution axes and it is defined by:**

$$P = 3\,[\text{ mean } - \text{ median }]\,/\,S \quad (9\text{-}27)$$

**It is seen that its value is approached from the normal distribution for the case (b) while it is more far for case (a). But the case (C) gives an abnormal condition for the shape of load curves in general where its value is positive. This leads to the great importance of such investigation (Fig. 9-6) so that the base of statistics may be essential for load curves presentation at all.**

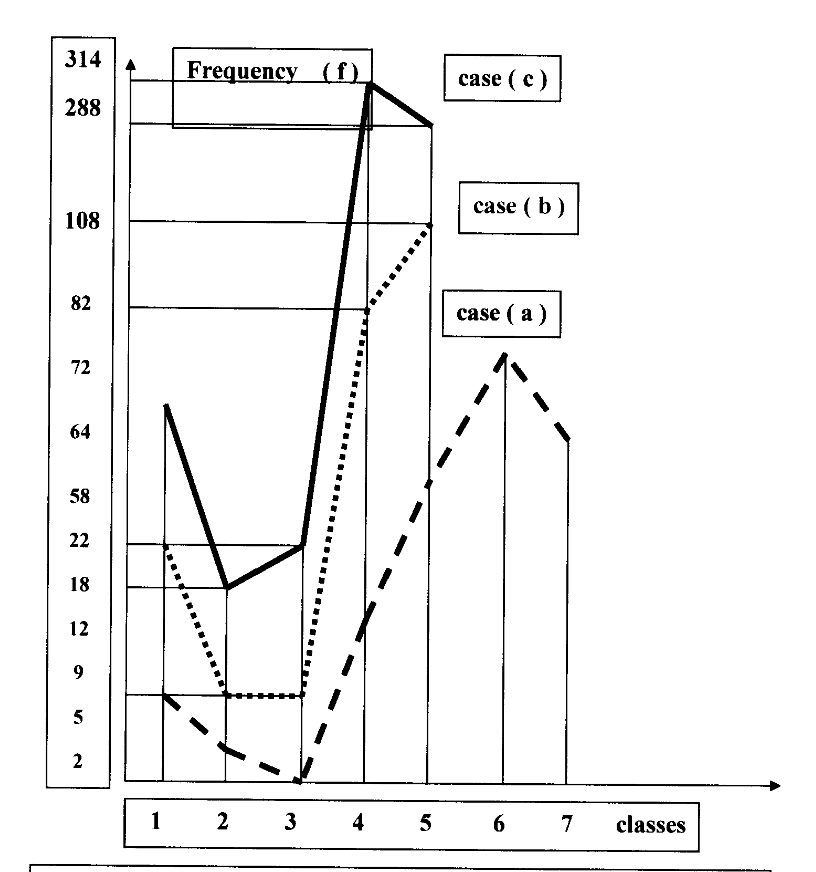



Fig. 9-6: The dependence of the frequency on classes for the cases studied

## 4- The Weight Loads Mean

**The effect of peak on the load curve appears to be the most important item for Engineers and so, the statistical study for either peak or light loads may be applied according to:**

$$X_w = [\Sigma X_i W_i] / \Sigma W_i \quad (9\text{-}28)$$

**The calculated values are drawn in Fig. 9-7 to prove that the peak is a heavy point in the design of a network with the load curve base.**

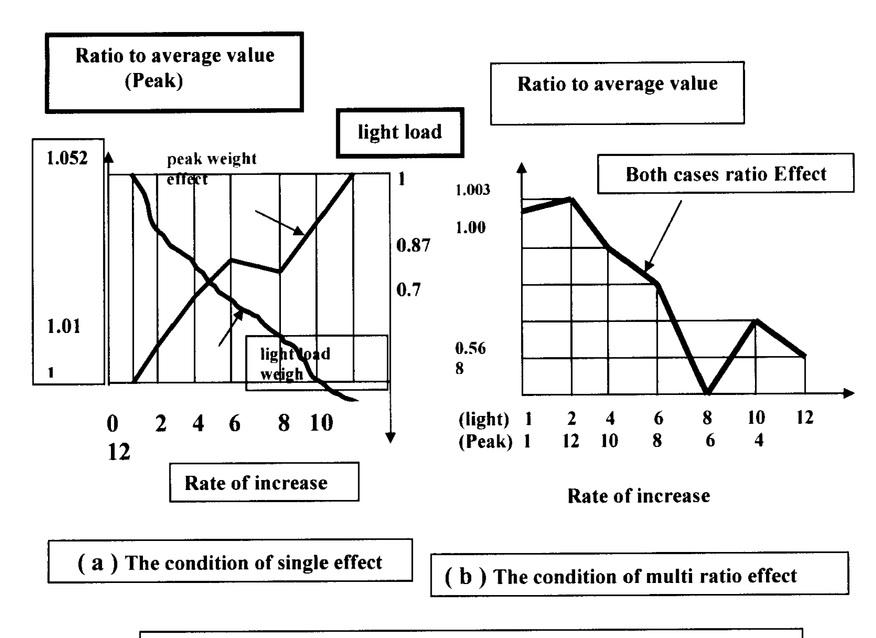



**Fig. 9-7: The effect of weight of the peak and light load**

## 5- CORRELATION FACTOR FOR LOAD CURVES

**Whatever, the load varied not only by time but also with the place because the end users are continuously increased day by day, and consequently, the load may be changed. The given above statistical data for the Sundays may illustrate that performance so that the skew factor is approached to be a normal distribution. This means that the characteristics of a certain day are stable while the general performance is widely changing. The statistical study leads to a new correlation due to the unused energy in the network in spite of the company reserve it for them. So, the unused energy must be shared with customers in the process of accounting. This correlation factor to load curve (Fig. 9-8) may be proposed to each or all consumers of the network as a function of the average load in the form:**

$$\beta = (\Sigma X / E_t) \qquad (9\text{-}29)$$

**Thus, the allowable energy to be generated will be included through the energy too inside the term of running cost of equation (9-13) while its installed value is**

**computed with the capital cost. This can balance the process of costing for the energy consumption.**

**Thus, the proposed correlation factor for the accounting process will be suitable to cover any deviation in the readings in the process of energy costing in Egypt even if it is a multi month measuring. This correlation does not touch the tariff base. It can be recommended for application in the software concerning this item. Another correlation factor is needed on the statistical bases to cover the variation performance of the load curves.**

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